Report

Task 4: Problem and Solution Identification and Prioritization for Holmes Run, Alexandria, Virginia

Prepared for

City of Alexandria

Transportation and Engineering Services

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CH2MHILL®

Executive Summary

The City of Alexandria, Virginia (the City) has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. The watersheds include Hooffs Run, Four Mile Run, Holmes Run, Cameron Run, Taylor Run, Strawberry Run, Potomac River, and Backlick Run.

This Report focuses on problem and solution identification (Task 4) for capacity issues in Holmes Run. It summarizes the problem identification steps, solution development, solution scoring, and alternatives analysis. This task has resulted in three watershed-wide alternatives aimed at resolving capacity-related problems in the Holmes Run Watershed. Additionally, this task has provided the City with a decision-making process for evaluating the benefits of potential stormwater management (SWM) projects.

The objectives of this phase of the study were to: (1) identify and prioritize capacity problems based on modeling results from Task 2 of this project and (2) develop and prioritize solutions to address those problems. In Hooffs Run, three different design criteria and one historical storm were examined during the Task 2 modeling analysis: (1) the City's existing intensity-duration-frequency (IDF) curve, (2) the updated curve using the full record of historical precipitation data available at the time of the analysis (1949 to 2008), (3) the curve projected for the year 2100 using various climate change scenarios, and (4) the June 25–27, 2006 storm event, estimated to be approximately a 20-year event based on volume and slightly less than a 10-year event based on peak intensity. The results of the Task 2 analyses showed that the existing IDF design hyetograph was the most conservative of the design storms (produced the greatest amount of stormwater runoff and flooding), and produced a similar amount of the system flooding to the results from the historic event. Consequently, this scenario was chosen to be used to complete the remainder of the project.

The first objective of the study, identifying and prioritizing problems, was accomplished in two steps. The first step included evaluation of each stormwater junction in the drainage network using a scoring system to identify problems based on several criteria, including: the severity of flooding, proximity to critical infrastructure and roadways, city staff and public identification of problems, and opportunity for overland relief. In the next step, high scoring junctions (i.e., higher priority problems) were grouped together to form high-priority problem areas. In total, nine high-priority problem areas were identified in the Holmes Run watershed. Flooding locations falling outside of the high-priority problem areas were either flooding at isolated structures, or did not score high on the scoring criteria. These flooding problems were not addressed by solutions in this project.

The second objective involved developing and prioritizing solutions to address capacity limitations within the nine high-priority problem areas. Several different strategies were examined to accomplish this objective, including improving conveyance by increasing hydraulic capacity, reducing capacity limitations by adding distributed storage to the system, and reducing stormwater inflows by implementing green infrastructure (GI). Each of these strategies required a different modeling approach. Conveyance improvements were modeled by increasing pipe diameter in key locations within the problem area, storage was added at storage nodes based on a preliminary siting exercise, and GI was modeled as a reduction in impervious area at three different implementation levels: high, medium, and low. A single model run was set up for each strategy including solutions for all nine high-priority problem areas and the results were compiled for the alternative and prioritization evaluation. Solutions were evaluated based on several criteria, including drainage improvement/flood reduction, environmental compliance, sustainability and social benefits, asset management and maintenance implications, constructability, and public acceptance. Planning level capital costs were developed for each solution to facilitate a benefit cost analysis and prioritization process.

The results of the solution identification and prioritization analysis show the following:

- In terms of solution technology performance:
  - GI generally has the greatest overall benefit as defined by the solution evaluation scoring system described in this report
  - Conveyance solutions and high implementation of GI generally provide the greatest flood reduction of the technologies/approaches analyzed in Holmes Run
  - Combination of conveyance or storage projects combined with GI generally provides the greatest benefit and flood reduction
- In terms of costs:
  - Low level of GI implementation generally has the greatest benefit /cost score but did not usually meet minimum threshold for flood reduction
  - Conveyance projects generally provide the most economical stormwater volume reduction in terms of dollars per gallon of flood reduction within a high-priority problem area
  - Combination of conveyance and GI generally provides the greatest overall benefit/cost score

Three watershed-wide alternatives were developed, including:

- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to address the worst problem areas to the extent practicable.

Alternative 1 was built on the objective of providing the best cost efficiency in each of the nine high-priority problem areas. This resulted in a higher total capital cost than Alternative 2, but reduced the flooding in the nine high-priority problem areas by about one million gallons over Alternative 2. Alternative 2 focused on the solutions that had the highest benefit/cost ratio in each of the nine high-priority problem areas. This focus resulted in the highest benefit/cost ratio and the lowest cost per million gallons of flood reduction of the three alternatives. Conversely, Alternative 2 resulted in the smallest flood volume reduction of the three alternatives. Alternative 3, which focused on providing the greatest overall relief within the nine high-priority problem areas, resulted in the highest overall benefit score and the greatest total flood reduction but at the highest cost. Therefore, Alternative 2 is the most beneficial and cost effective watershed-wide alternative. A summary of the results is provided in Table ES-1. As the most cost-effective alternative, model results for Alternative 2 and the existing conditions model are presented in Figures ES-1 and ES-2.

TABLE ES-1
Watershed-wide Alternatives Scoring and Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

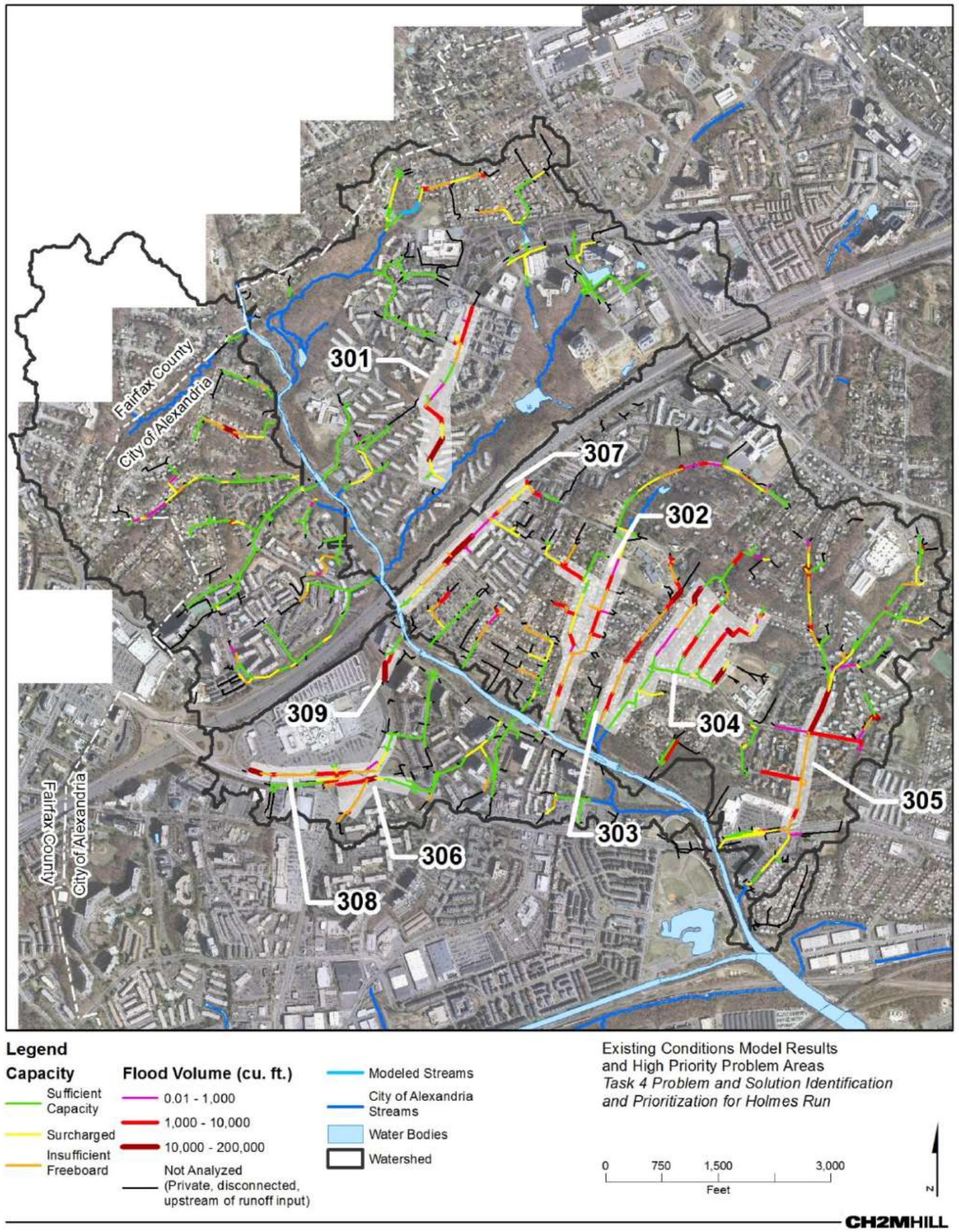
	Alternative 1 - Best Cost Efficiency	**Alternative 2 - Best Benefit/Cost Ratio**	**Alternative 3 – Highest-priority Problems**
Total Capital Cost ($ Millions)	$8.30	$5.76	$18.97
Total Benefit Score	404	433	445
Overall Benefit/Cost	48.7	75.1	23.5
Total Flood Reduction (MG)	3.620	2.780	4.743
Cost of Flood Reduction ($/Gallon)	$2.29	$2.07	$4.00

When developing a capital improvement plan, the benefit cost or cost efficiency ($/gallon of flood reduction) are typically used to guide the order in which projects are implemented. Prioritization results for Alternative 2 are presented in Figure ES-3. The top chart shows the total benefit score and the cumulative capital cost of the alternative. The solutions are provided in order of decreasing benefit cost ratio; solutions with the greatest benefit cost are presented on the left and solutions with the lowest benefit cost are presented on the right. The bottom chart shows the benefit/cost ratio for each solution in the watershed-wide alternative in order of increasing cost/gallon of flood reduction. Both charts show the cumulative capital cost plotted on the secondary axis. The solutions on both charts are named by the technology: conveyance (CONV), storage (STOR), low green infrastructure (LGI), medium GI (MGI), or high GI (HGI), and the problem area number.

It should be noted that the model does not include analysis on private property, but applies assumed runoff loads as inputs to the public conveyance system. The City chose not to include existing private or most public stormwater management facilities (e.g., detention and retention ponds) upstream of the modeled collection system, as identified in the Task 2 TM, because of the limited available information on these facilities and a concern that the facilities may not be performing as designed. When the City moves forward into detailed evaluation and design of selected projects it will be important to fully evaluate and account for the benefits of any existing stormwater management facilities.

The hydraulic modeling results and costs presented in this Report should be reviewed with the understanding that several assumptions were made to fill data gaps in the hydraulic model, and proposed solutions and costs were developed on a planning level.

FIGURE ES-1
Existing Conditions Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



FIGURES ES-2
Alternative 2: Best Benefit/Cost Ratio Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

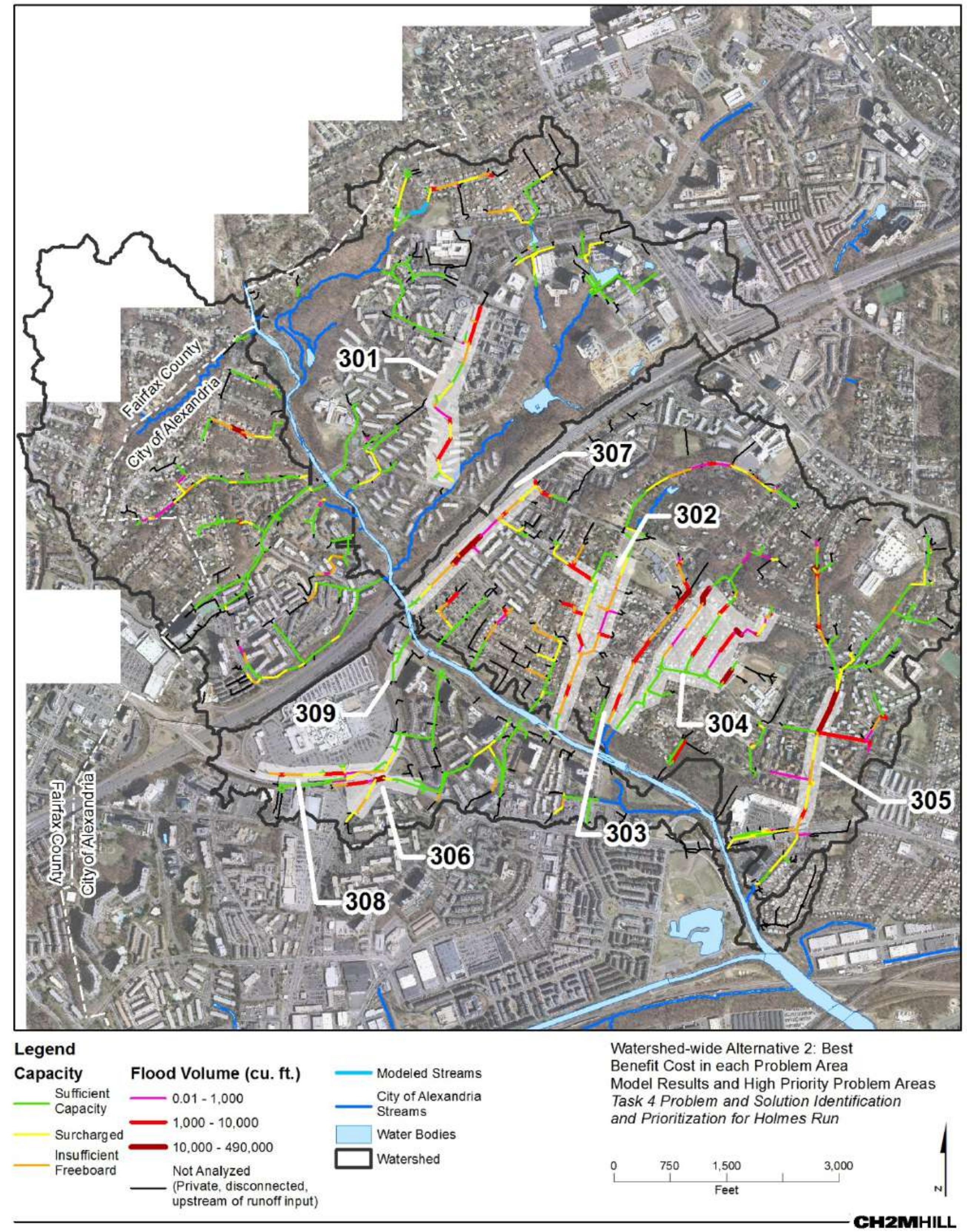
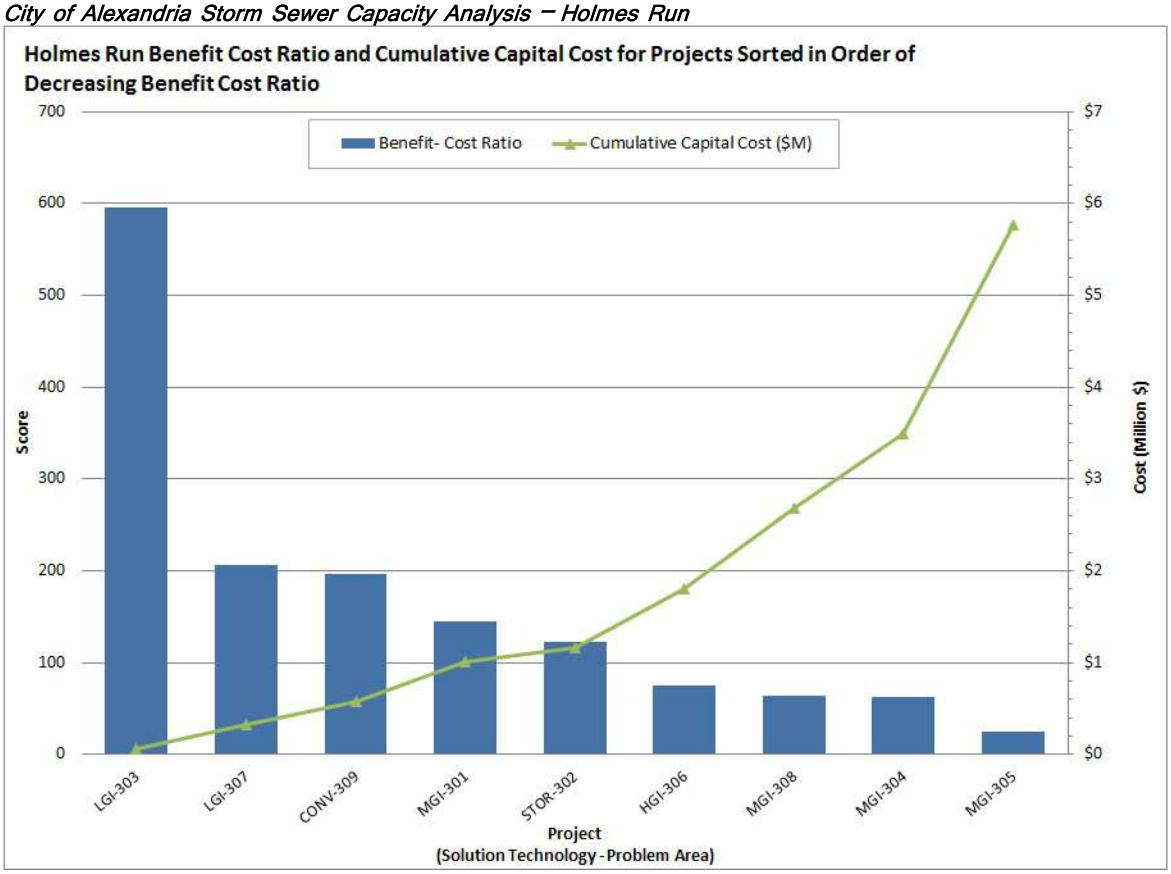
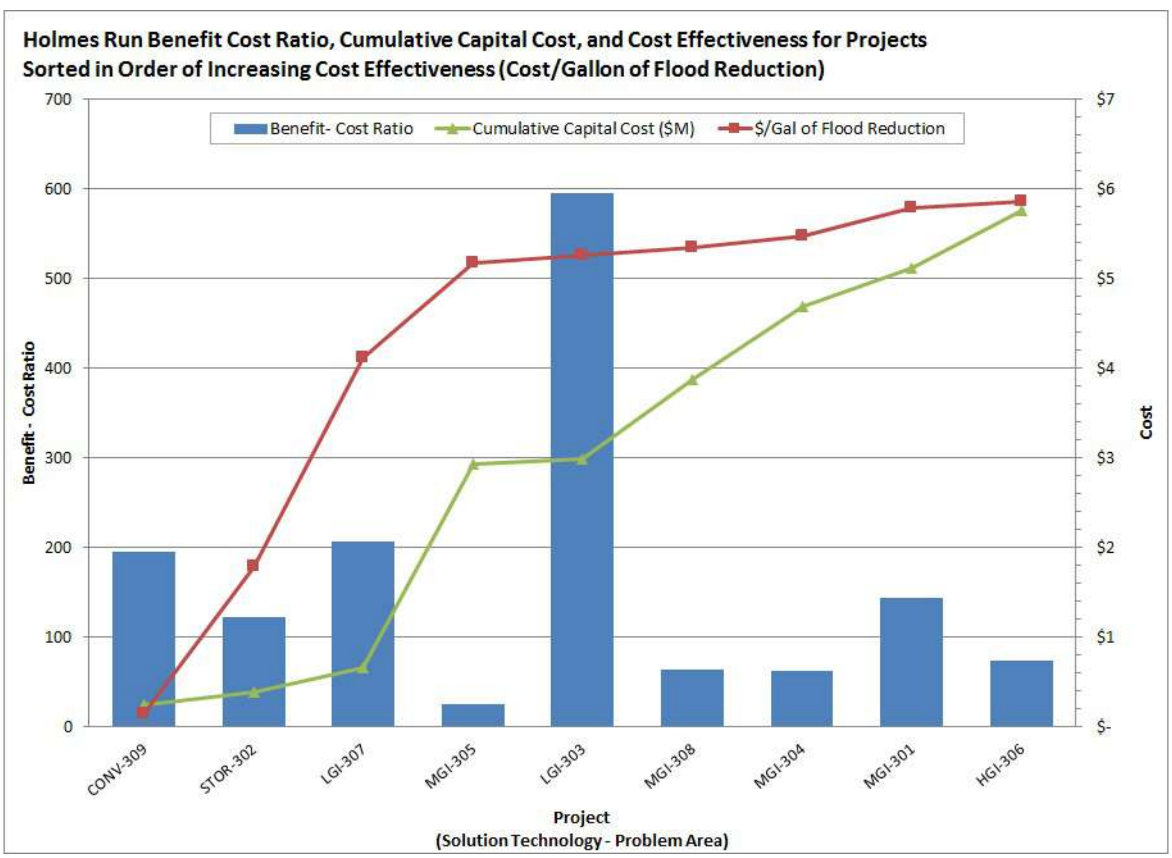


FIGURE ES-3
Alternative 2: Best Benefit/Cost Ratio Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run





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Figures

Acronyms and Abbreviations

bgs	below ground surface
cfs	cubic feet per second
City	City of Alexandria, Virginia
ft^2	square feet
ft^3	cubic feet
GI	green infrastructure
HGI	high green infrastructure
HGL	hydraulic grade line
hrs	hours
ID	identification
IDF	intensity-duration-frequency
LF	linear feet
LGI	low green infrastructure
MG	million gallons
MGI	medium green infrastructure
ROW	right-of-way
SWM	stormwater management
TM	technical memorandum

SECTION 1

Introduction

The City of Alexandria, Virginia has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed, starting with Hooffs Run and continuing with Holmes Run, which is the subject of this Report. City of Alexandria watersheds are shown on Figure 1-1.

1.1 Background

The project consists of four major subtasks related to the model development and modeling. These four tasks and related TMs are described below.

- Task 1 – Review and propose revisions to the City's stormwater design criteria.
  - *Updated Precipitation Frequency Results and Synthesis of New IDF Curves for the City of Alexandria, Virginia* (CH2M HILL, 2009a)
  - *Sea Level Rise Potential for the City of Alexandria, Virginia* (CH2M HILL, 2009b)
  - *Rainfall Frequency and Global Change Model Options for the City of Alexandria* (CH2M HILL, 2011)
- Task 2 – Analyze the City's stormwater collection system capacity.
  - *Stormwater Capacity Analysis for Holmes Run Watershed, City of Alexandria, Virginia* (CH2M HILL, 2016a)
  - *Inlet Capacity Analysis for City of Alexandria Storm Sewer Capacity Analysis* (CH2M HILL, 2012)
- Task 3 – Survey collection system facilities on pipes 24 inches and larger to fill data gaps.[1]
  - *City of Alexandria Storm Sewer Capacity Analysis (CASSCA) Holmes Run Condition Assessment* (Baker, 2013)
- Task 4 – Identify problem areas and suggest solutions.
  - *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014)

1.2 Objectives

Tasks 1 through 3 focused on model development and capacity analysis of the existing system. The purpose of Task 4 is to identify and prioritize problems modeled during the Task 2 capacity analysis and to suggest and prioritize conveyance, storage, and GI solutions to resolve the identified capacity limitations.

This Report describes the methodology and results of Task 4 for the stormwater collection system in the Holmes Run Watershed. Figure 1-1 presents the City of Alexandria's stormwater drainage watersheds.

[1] Though originally intended to improve data quality where the model predicted capacity limitations, the scope of Task 3 was expanded, and field survey was completed prior to Task 2 to fill data gaps and to improve the model development process.

FIGURE 1-1
Stormwater Drainage Watersheds, City of Alexandria, Virginia
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

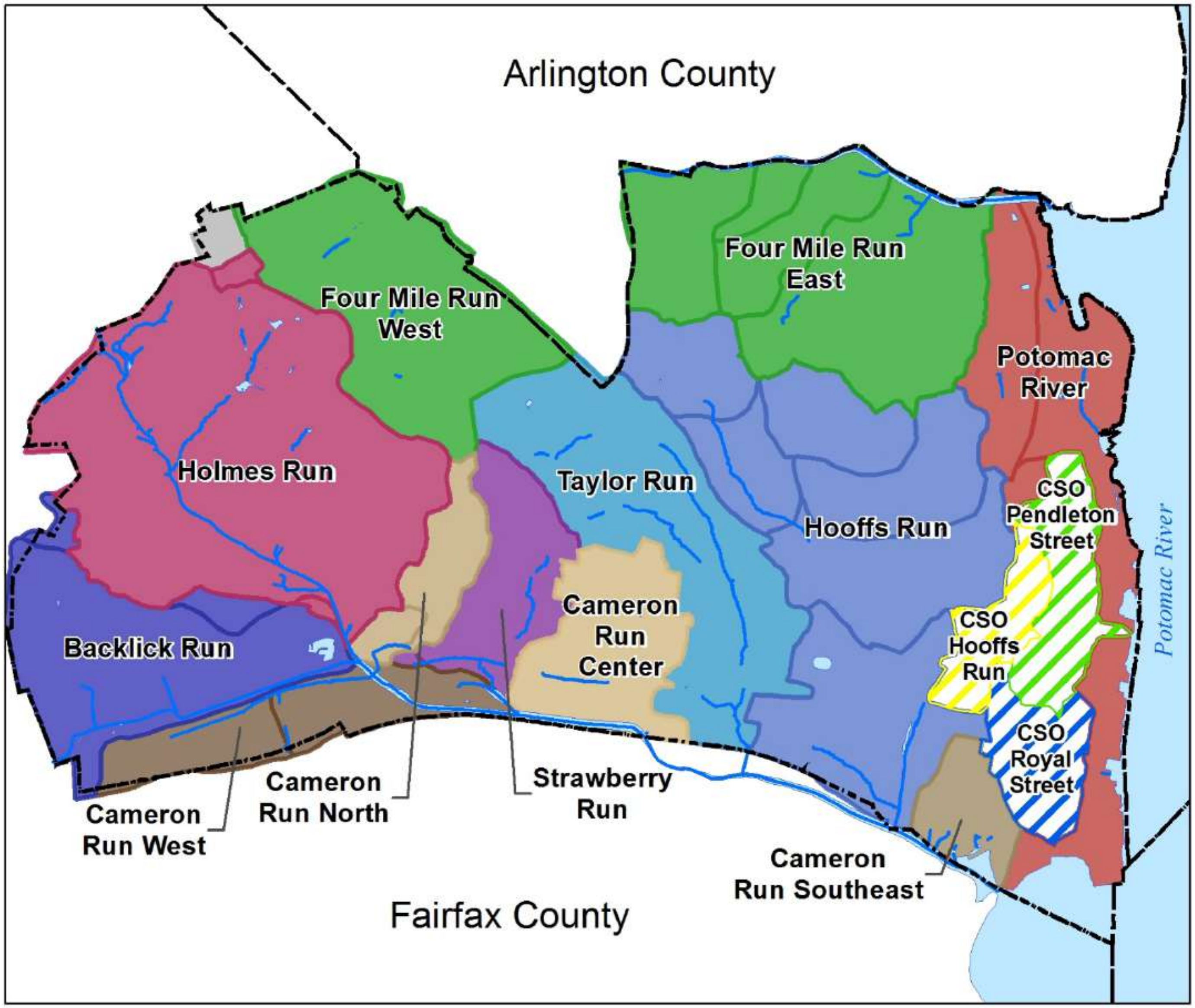

FIGURE 1
City of Alexandria Stormwater
Drainage Watersheds
Task 4 Problem and Solution Identification
and Prioritization for Holmes Run
Alexandria, Virginia

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SECTION 2

Approach

The approach to identifying and prioritizing problems and solutions included several distinct steps: identification and prioritization of problems, development and modeling of solutions, prioritization of solutions and, finally, development of watershed-wide scenarios. This approach, described in this section, is broken into two major components: prioritization and modeling.

2.1 Prioritization

The focus of Task 4 is prioritization of problem areas based on Task 2 modeling results, development of solutions to alleviate the problems within the problem areas, then prioritization of solutions. Prior to beginning the Task 4 analysis, City of Alexandria staff and consultants from the CH2M HILL team convened in a workshop on November 14, 2012 to discuss the objectives, approach, and desired outcomes of this phase of the project. The major objectives of the workshop were to define the prioritization process, identify the key evaluation criteria for scoring and ranking problems and solutions, and define relative criteria weights. The prioritization process, described below, is similar for both problems and solutions and includes several distinct steps.

- **Define evaluation criteria**: Evaluation criteria for problems and solutions were defined during the Task 4 workshop with input from City of Alexandria staff from the Engineering & Design, Office of Environmental Quality, and Maintenance Divisions of Transportation and Engineering Services. These criteria, which are summarized in this Report, were used to assess the severity of problems and the benefit of solutions.

- **Weight evaluation criteria**: Each evaluation criterion was assigned a weight (0 to 100) by Task 4 workshop participants. The weights quantify the relative importance of each evaluation criteria and build a defensible foundation for problem and solution ranking.

- **Define scoring system**: A scoring system was developed for each evaluation criteria. This provided a method for ranking problems and solutions within evaluation criteria. Scoring systems for problem area and solution evaluation criteria are defined in this report.

- **Score and rank alternatives**: Problems and solutions were scored and ranked using the evaluation criteria scoring systems, which are described in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014) and include:

  - *Score and Rank Problems:* A score of 0 through 10 was assigned to stormwater junctions in the modeled system for each evaluation criteria. Weights were then applied to the score calculated for each evaluation criteria to come up with an overall weighted score for each junction. The overall score was used to rank problems, then high-priority problem areas were identified as groupings of hydraulically connected junctions and pipes. Solutions were investigated for the highest-priority problem areas.

  - *Score and Rank Solutions*: Solutions were developed for high-priority problem areas identified in the previous step. A score of 0 through 10 was assigned to solutions for each evaluation criteria. Then the weights were applied to the score calculated for each evaluation criteria to calculate an overall weighted benefit score. Solutions were ranked based on the overall score as well as the cost/benefit score, which is the overall benefit score divided by the capital cost of the solution. The solution evaluation is presented at the end of this report.

- **Perform "what-if" analysis to refine process**: After completing the prioritization, the process was examined to ensure the results met the expectations of the City. The result of this step was the inclusion of a 22 percent minimum threshold for flood reduction (any project that produced less than 22 percent reduction in flooding was eliminated) to help focus the solution identification process. This threshold was selected by City of Alexandria staff based on best engineering judgment.

- **Evaluate watershed-wide scenarios**: Once individual solutions were evaluated, the solutions were grouped into three alternative watershed-wide scenarios. The scenarios were scored by summing scores and costs of individual projects for comparison. The purpose of taking this watershed-wide look at solution sets was to evaluate the solutions in a holistic, system-wide manner to evaluate composite impacts of implementing various solutions across the system and to support selection of a set of solutions that will provide the greatest benefit for the least cost.

2.1.1 Problem Area Evaluation

The problem area evaluation focused on identifying flooding problems that are extreme and/or in proximity to critical facilities. Though model results were presented for pipes, not junctions, in the Stormwater Capacity Analysis (Task 2), flooding occurs at a junction and not along the length of the pipe; therefore, stormwater junctions in the hydraulic model, not pipe segments, were scored for each of the problem area evaluation criteria. Raw scores for each criterion ranged from 0 to 10, 0 indicating the junction is not a priority and/or the evaluation criteria is not applicable, and 10 indicating the junction is a high-priority. The problem area evaluation criteria include:

- Urban drainage/flooding
- Identification of problems by the public
- Identification of problems by city staff
- Proximity to critical infrastructure
- Proximity to critical roadways
- Opportunity for overland relief

Detailed descriptions of the problem scoring systems used in this evaluation are provided in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014). The weighted score was computed using the raw score and normalized percent weight. Evaluation criteria and weights developed and agreed upon during the Task 4 Workshop are presented in Table 2-1.

TABLE 2-1
Problem Area Evaluation Criteria and Weights
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area Evaluation Criteria	Weight	Normalized % Weight
Urban Drainage/Flooding	90	23.1
Public ID of Problem	73	18.8
City Staff ID of Problem	75	19.3
Proximity to Critical Infrastructure	58	14.9
Proximity to Critical Roadways	38	9.8
Opportunity for Overland Relief	55	14.1
Total	**389**	**100**

After computing the weighted score for each junction, high-priority problem areas were identified as hydraulically connected groupings of junctions and pipes for the junctions with scores in the top 12 percent of scores over 0. Scoring was based on results from the Task 2 model of the 10-year, 24-hour storm generated using the existing IDF. The results of the problem area evaluation are presented in the Problem Identification section.

The goal of delineating high-priority problem areas was to identify groupings of stormwater pipes causing capacity limitations so that conveyance, storage, and GI solutions could be developed for the area. This task was accomplished by starting with the highest-ranked junction score, which indicated it was the worst problem based on the problem area identification evaluation criteria, and reviewing the surrounding drainage network and model results to identify the pipes and junctions related to that high problem score. A polygon surrounding all the pipes related to the capacity limitation was digitized in ArcMap and was assigned a unique identifier. After completing this process for the highest-ranked junction score, the network and model results for the next-highest score were examined, and a new problem area was digitized, however, if the next highest-score was captured in the first high-priority area, it was skipped. This process was repeated for junctions with a score above 30, or the top 3 percent of junctions with a score over 0. Flooding locations falling outside of the high-priority problem areas were either flooding at isolated structures, or did not score high on the scoring criteria. These flooding problems were not addressed by solutions in this project.

2.1.2 Solution Evaluation

Solutions were developed to resolve or improve capacity limitations in the highest-priority problem areas. Three different technologies were evaluated: conveyance, storage, and GI. Modeling results, described in detail in the following sections, were used in conjunction with additional data from the City (for example, geospatial data on roads and critical infrastructure, capital improvement plans, maintenance plans) to score solutions for each of the following solution evaluation criteria:

- Urban drainage/flooding
- Environmental compliance
- EcoCity goals/sustainability
- Social benefits
- Integrated asset management
- City-wide maintenance implications
- Constructability
- Public acceptability

Detailed descriptions of the solution scoring systems used in this evaluation are provided in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014). The weighted score was computed using the raw score and normalized percent weight. Evaluation criteria and weights agreed upon during the Task 4 workshop are presented in Table 2-2.

TABLE 2-2
Solution Evaluation Criteria and Weights
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Solution Evaluation Criteria	Weight	Normalized % Weight
Urban Drainage/Flooding	95	17.1
Environmental Compliance	93	16.8
EcoCity Goals/Sustainability	50	9.0
Social Benefits	40	7.2
Integrated Asset Management	73	13.2
City-wide Maintenance Implications	90	16.2
Constructability	60	10.8
Public Acceptability	53	9.6
Total	**554**	**100**

2.2 Modeling

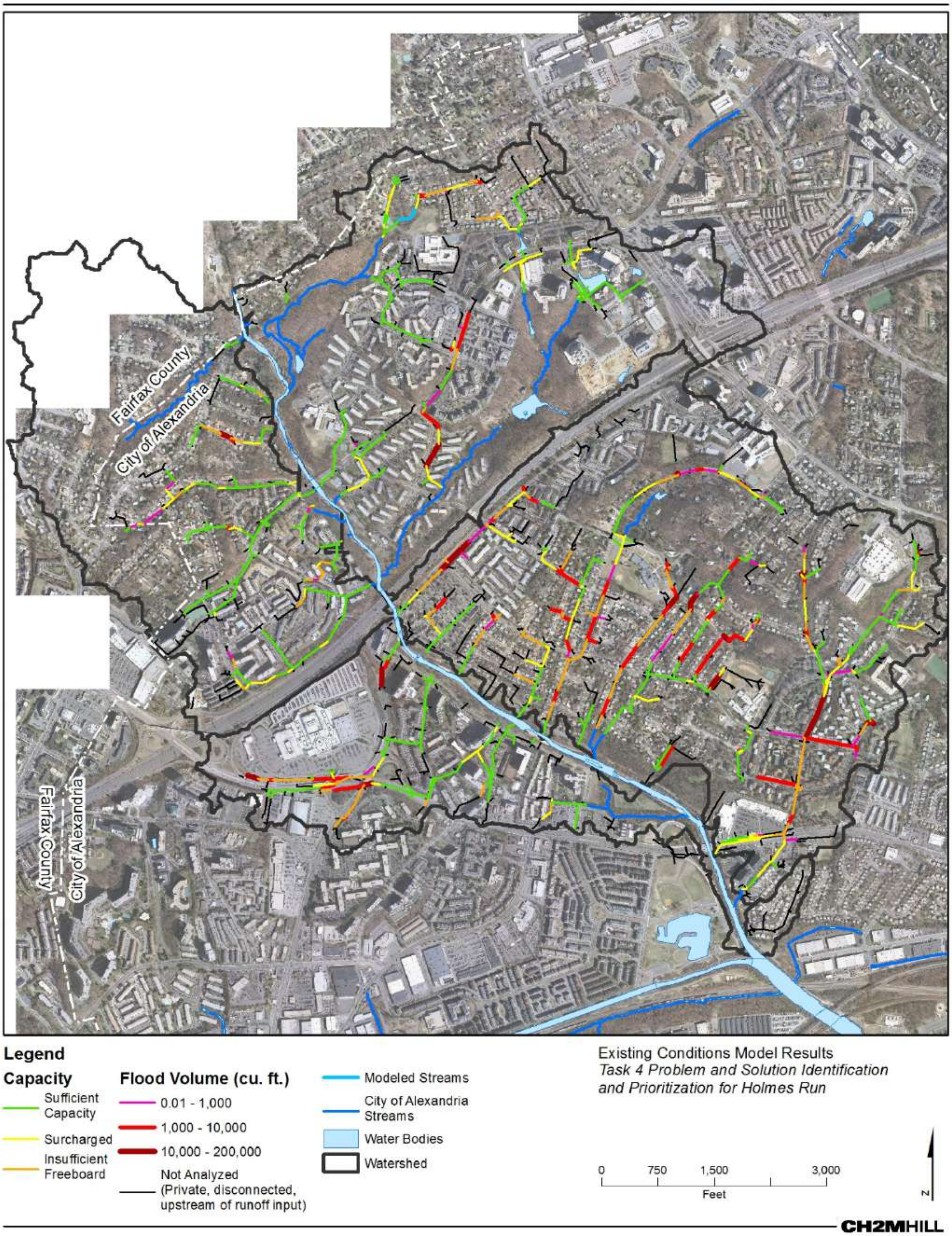
To support the Task 4 analysis, the Holmes Run Watershed capacity was analyzed using commercially available and public domain computer models that are widely used and industry-accepted. The details of the hydrologic and hydraulic modeling are documented in the Task 2 TM, *Stormwater Capacity Analysis for Holmes Run Watershed, City of Alexandria, Virginia* (CH2M HILL, 2016a). The existing conditions model of the 10-year, 24-hour design storm based on the City's existing IDF curve served as the basis for modeling in the Task 4 analysis. Table 2-3 and Figure 2-1 present the Task 2 results for reference.

TABLE 2-3
Summary of Task 2 Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Existing Conditions Results			
	Conduit Length (LF)	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**
Sufficient Capacity	46,462	47	-	-
Surcharged[a]	18,181	19	255	-
Insufficient Freeboard	15,282	16	-	-
Flooded	18,093	18	92	900,744

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

FIGURE 2-1
Task 2 Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



2.2.1 Baseline Improvements and Major Capacity Solutions

In Hooffs Run several baseline improvements and major capacity solutions were identified and addressed prior to evaluating solutions in the rest of the system. The goal of identifying baseline improvements was to remove hydraulic limitations that may have negatively affected the ability to model solutions.

Profiles of the Holmes Run existing conditions model results were reviewed to identify significant changes in diameter or slope over relatively short distances where there was also a sudden increase in the hydraulic grade line(HGL). In addition to reviewing the profiles, the data sources for invert and diameter information were reviewed. There were no locations identified in the Holmes Run watershed that required baseline improvements. Additionally, there were no locations identified within the Holmes Run watershed where extreme capacity limitations caused long backwater conditions and substantial flooding in the system. Therefore, there was no need for developing solutions for major capacity problems.

2.2.2 Alternative Solutions

The purpose of this task was to identify and evaluate corrective measures that could be undertaken to reduce flooding and improve stormwater quality through the use of green infrastructure practices. In addition, there is the potential to achieve other ancillary benefits such as improved aesthetics, urban heat island reduction, and carbon capture through context sensitive solutions. Potential solutions were developed for each of the following project types or technologies, where applicable:

- Conveyance improvements
- Storage (modeled as underground storage, but could also be implemented as above ground storage or other conventional stormwater management approaches
- GI

The goal of the conveyance solutions was to evaluate the impact of increased conveyance capacity on flooding and surcharge in the high-priority problem areas. Conveyance improvements were modeled in xpswmm by increasing pipe diameter up to 0.1-foot below ground surface (bgs). The invert elevations and alignment of existing pipes were not altered, so pipe slope did not change from existing conditions. Because the goal of this evaluation was not to design solutions but to evaluate potential strategies and technologies, more detailed design will be required to develop fully implementable projects, including adjusting pipe shapes, providing parallel pipes, and providing for adequate ground cover.

The storage solutions involved evaluating the potential for new detention or retention facilities or offline storage for high-priority problem areas. Because of the dense urban development prevalent in the City of Alexandria, conventional SWM practices were assumed to be limited to offline subsurface storage facilities in the hydraulic model. Opportunities for subsurface storage were identified in open spaces, such as parking lots, green spaces, and grassed medians, with a preference for City-owned properties. Storage was modeled in xpswmm using storage nodes and weirs to model the overflow from a manhole into storage. The maximum storage size was determined by measuring the surface area of the open space available for storage and estimating the storage depth based on the manhole to which the storage system would be dewatered. It was assumed that storage should be a minimum of 3 feet deep and a maximum of 10 feet deep to maintain reasonable construction costs. Additionally, storage was only considered if gravity dewatering to a manhole within 1,000 feet was possible. Storage facilities would not be dewatered until the system had capacity to convey the stored flow. As such—and considering the focus of the modeling was to identify capacity limitations and flooding problems—storage dewatering was not evaluated in this analysis.

GI was evaluated at three different implementation levels: low, medium, and high. In the xpswmm model, GI was modeled by reducing impervious cover in model subcatchments. The low implementation level was modeled as a 10 percent reduction in impervious area, the medium at a 30 percent reduction, and the high at a 50 percent reduction. During development of the modeling approach soil and depression storage parameters were evaluated for sensitivity in the model. Ideally, these parameters would be adjusted to more accurately represent the physics of GI performance in the field. However, this level of detail in modeling was beyond the scope of this study, and infiltration parameters were not altered when modeling GI.

Table 2-4 describes the modeling approach and basic assumptions for each of the solution technologies. Solutions developed for each high-priority problem area are described in greater detail in the Solution Identification section of this Report.

TABLE 2-4
Description of Solution Modeling Approaches and Assumptions
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Solution Technology/Strategy	Modeling Approach	Basic Assumptions
Conveyance	Increase Pipe Diameter	Use existing slope and pipe alignment. Increase pipe diameter to a maximum of 0.1 foot bgs. Add barrels as necessary.
Storage	Add storage node with weir to convey flow into storage	Storage depth is between 3 feet and 10 feet bgs. Gravity dewatering is required. A 20-foot-long weir to storage with discharge coefficient of 3 is required. Only surcharged flow will be sent to storage.
GI	Decrease catchment impervious area	Low implementation: 10 percent reduction in impervious area. Medium implementation: 30 percent reduction in impervious area. High implementation: 50 percent reduction in impervious area.

Solution alternatives were modeled in xpswmm. The basis for the solution models was the Task 2 existing conditions model.

Using the Task 2 model as the existing conditions, alternative solutions were evaluated in five different models, one for each technology/strategy:

- Conveyance solutions model
- Storage solutions model
- Low GI implementation model
- Medium GI implementation model
- High GI implementation model

This approach has limitations when projects are in proximity to one another; because the hydraulics are inextricably linked. However, because of the number of solutions and technologies being evaluated, evaluating each project independently was not within the scope of the analysis. In the Holmes Run watershed there were limited hydraulic interactions between the problem areas.

SECTION 3

Problem Identification

The purpose of the problem identification task was to assign a score to structures in the stormwater drainage network so that high-priority problem areas could be identified. Solution alternatives were developed for high-priority problem areas in the Holmes Run Watershed. Junctions were scored for each of the problem area evaluation criteria. Table 3-1 shows the distribution of scores across the 1,782 stormwater junctions that were modeled in Holmes Run. These results were generated using the Task 2 existing condition model (existing IDF, existing boundary conditions) with the model described in the Approach section of this report.

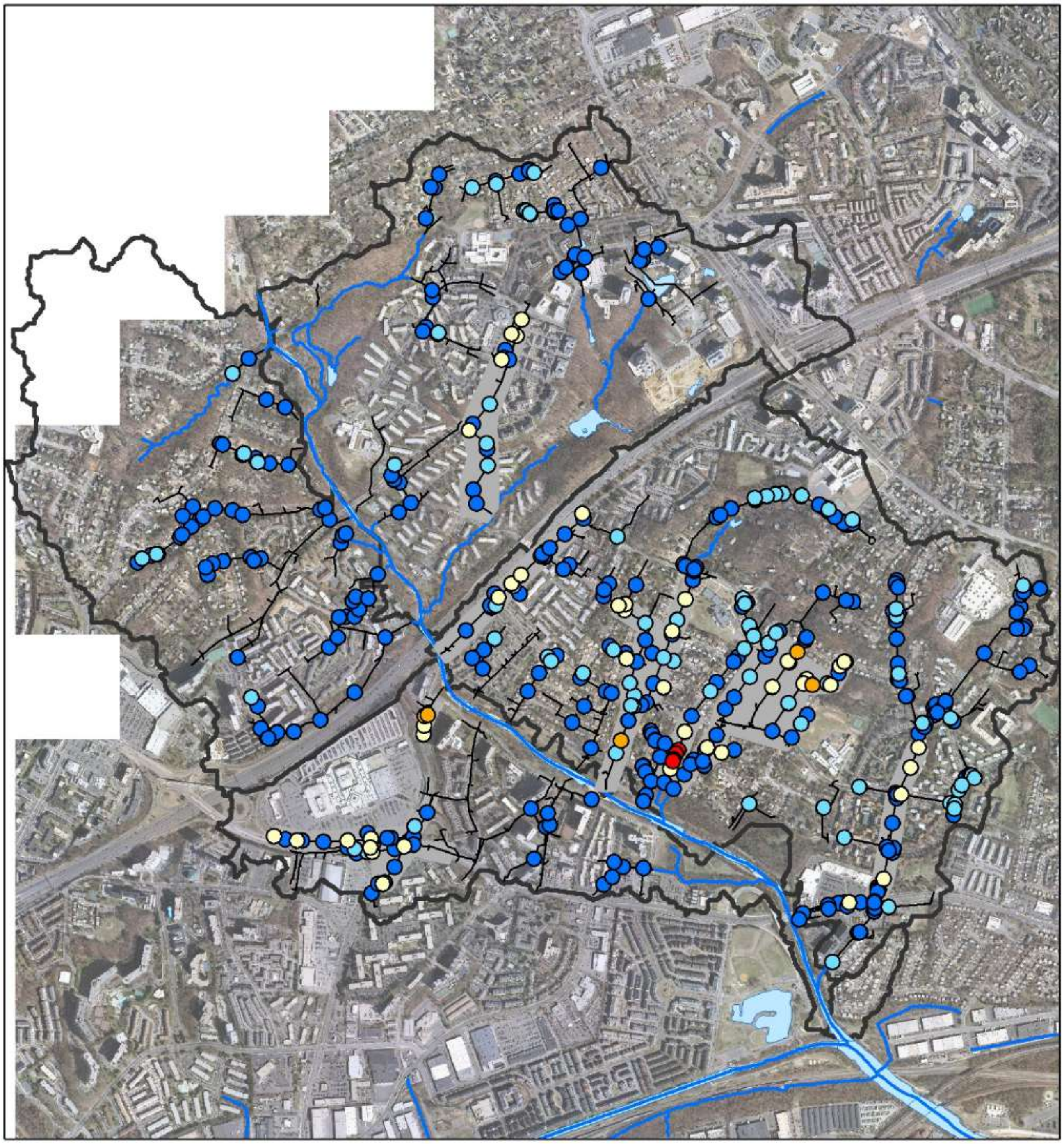
TABLE 3-1
Holmes Run Problem ID Scores
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem ID Score	Count of Junctions	% of Total
0	1,340	75.2
0.1–20	307	17.2
20.1–30	81	4.5
30.1–40	45	2.5
40.1–50	5	0.3
>50.1	4	0.2
Total	**1,782**	**100**

A map of the junction scores is provided on Figure 3-1.

After scoring individual junctions, high-priority problem areas were identified as groupings of hydraulically connected junctions and pipes in proximity to one another. A total of nine high-priority problem areas were identified in Holmes Run and are shown on Figure 3-1.

FIGURE 3-1
Holmes Run Problem Identification Score Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



Legend

Junction Score
- 0.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- > 50.1

- DGravityMain
- City of Alexandria Streams
- Water Bodies
- Subwatersheds

Note: Junction scores of 0 not shown.

Junction Scores for Existing Conditions Model
Task 4 Problem and Solutoin Identification and Prioritization for Holmes Run

0 750 1,500 3,000
Feet

N

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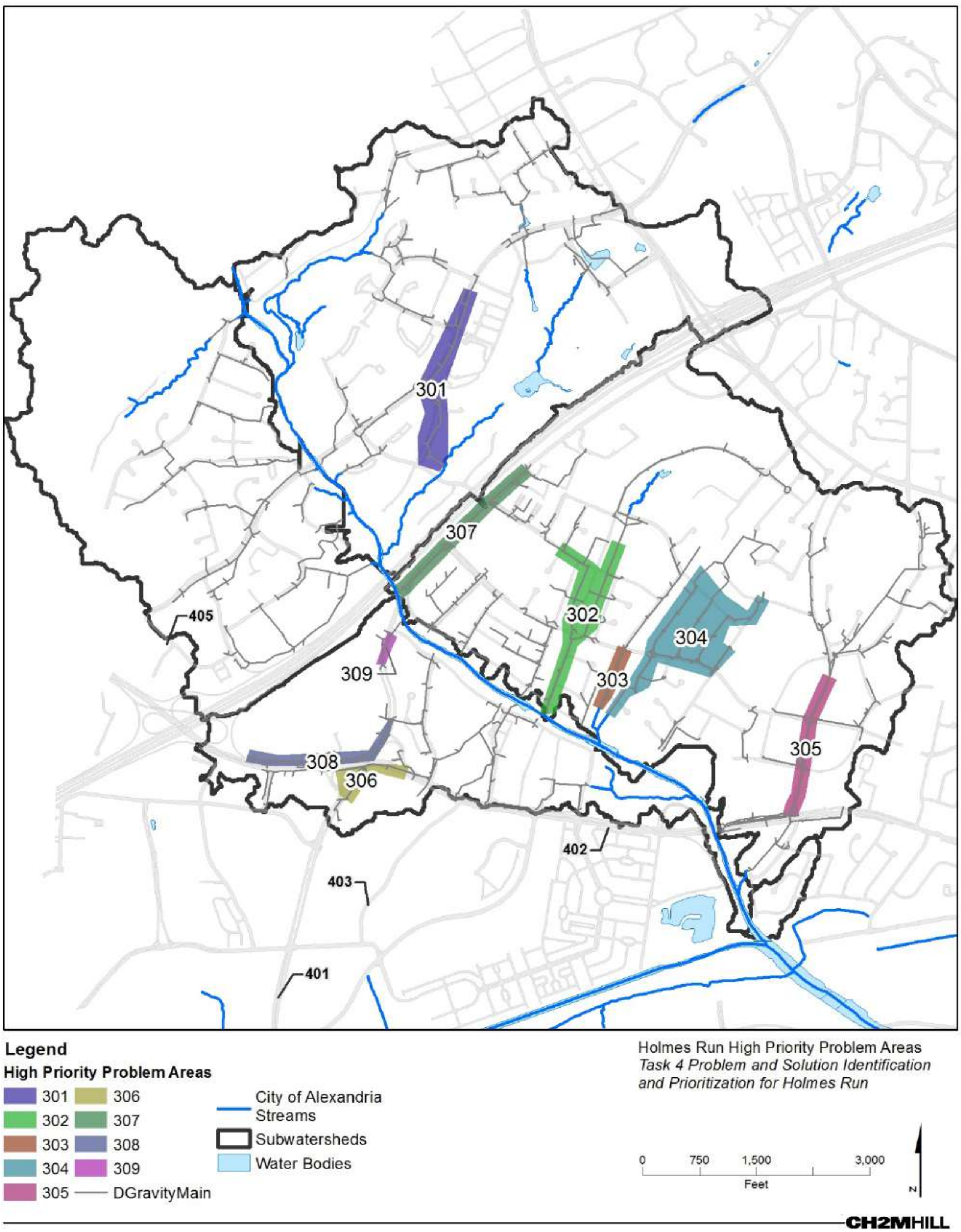
FIGURE 3-2
Location of Holmes Run High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



SECTION 4

Solution Identification

A suite of solutions, including conveyance, conventional SWM (modeled as storage), and GI projects, was developed for each problem area. The solution identification process resulted in 37 unique projects for the nine high-priority problem areas in the Holmes Run Watershed. Solutions were focused on the high-priority problem areas, therefore flooding outside those problem areas would not necessarily be addressed by any of the alternatives. For example, in Figure 3-2, there are segments of pipes located north of Problem Area 305 that experience some flooding but the Problem ID scores for this area are lower than the 30 point threshold. There is no critical infrastructure in the area, no public or staff identification of the problems and there is good overland relief. Hence solutions were not developed for this area. The following section describes the specific solutions developed for each problem area by project type, as well as the model results.

4.1 Conveyance Solutions

A conveyance solution was developed for each of the high-priority problem areas. The goal of the conveyance solutions was to remove hydraulic limitations in the drainage network by increasing the capacity of the pipes in high-priority problem areas. Because this was a high-level conceptual exercise rather than a design exercise, the pipe alignment and roughness were left unchanged, and capacity was increased solely by increasing the pipe size. In most cases, pipe shape was not altered except where sufficient capacity could not be achieved because of limited cover or where the existing pipe was a special shape, such as horizontal elliptical pipes. Where there was limited cover, circular pipes were changed to box culverts so that capacity could be increased without daylighting. Special pipe shapes were converted to equivalent-diameter circular pipes to simplify the model and calculations.

The conveyance capacity required was estimated using xpswmm. A hydraulic model was used to approximate the unconstrained peak flow in each pipe segment by upsizing pipes to 0.1-foot bgs to maximize diameter without daylighting the pipe, and by increasing the number of barrels by a factor of 2 across the board. The resulting unconstrained peak flow and Manning's equation were used to back-calculate the diameter required for the pipe to flow less than 80 percent full.

In the high-priority problem areas, the required diameter was compared to the existing diameter. Pipes that were smaller than the required pipe size calculated using the unconstrained peak flow were upsized and included in the conveyance project. Pipes that had sufficient capacity under existing conditions were left unchanged. Pipe size was not optimized during this exercise, and runs of pipes were not consistently sized. A summary of the length of pipe and range of pipe sizes included in each conveyance solution is included in Table 4-1. A table documenting the existing and proposed diameter of each pipe segment is provided in Appendix A.

TABLE 4-1
Summary of Conveyance Projects
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

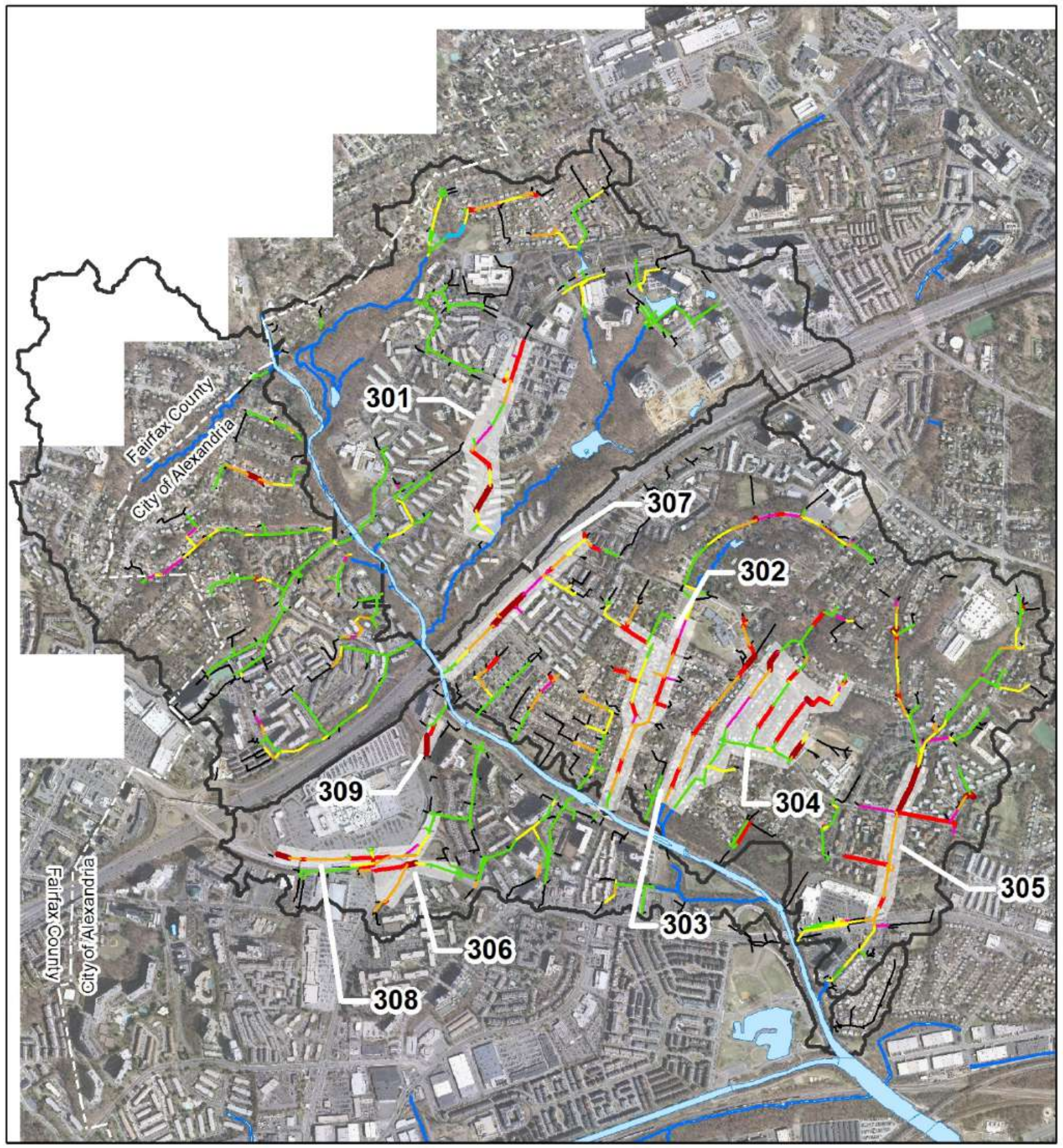
Problem Area ID	Project ID	Replacement Pipe Size Range and Project Description	Length (LF)
301	CONV-301	24-54 Inch Replacement Sewer Pipe Relief	2,731
302	CONV-302	30-90 Inch Replacement Sewer Pipe Relief	4,215
303	CONV-303	30-60 Inch Replacement Sewer Pipe Relief	863
304	CONV-304	18-72 Inch Replacement Sewer Pipe Relief	6,126
305	CONV-305	36-102 Inch Replacement Sewer Pipe Relief	1,976
306	CONV-306	24-36 Inch Replacement Sewer Pipe Relief	1,473

TABLE 4-1
Summary of Conveyance Projects
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area ID	Project ID	Replacement Pipe Size Range and Project Description	Length (LF)
307	CONV-307	42-78 Inch Replacement Sewer Pipe Relief	2,292
308	CONV-308	24-54 Inch Replacement Sewer Pipe Relief	2,199
309	CONV-309	42-48 Inch Replacement Sewer Pipe Relief	447

A map of the results of the existing conditions model results is provided on Figure 4-1 for reference, and map of the conveyance solution model results is provided on Figure 4-2. A summary of the results is provided in Table 4-2.

FIGURE 4-1
Existing Conditions Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



Legend

Capacity
- Sufficient Capacity
- Surcharged
- Insufficient Freeboard

Flood Volume (cu. ft.)
- 0.01 - 1,000
- 1,000 - 10,000
- 10,000 - 200,000
- Not Analyzed (Private, disconnected, upstream of runoff input)

- Modeled Streams
- City of Alexandria Streams
- Water Bodies
- Watershed

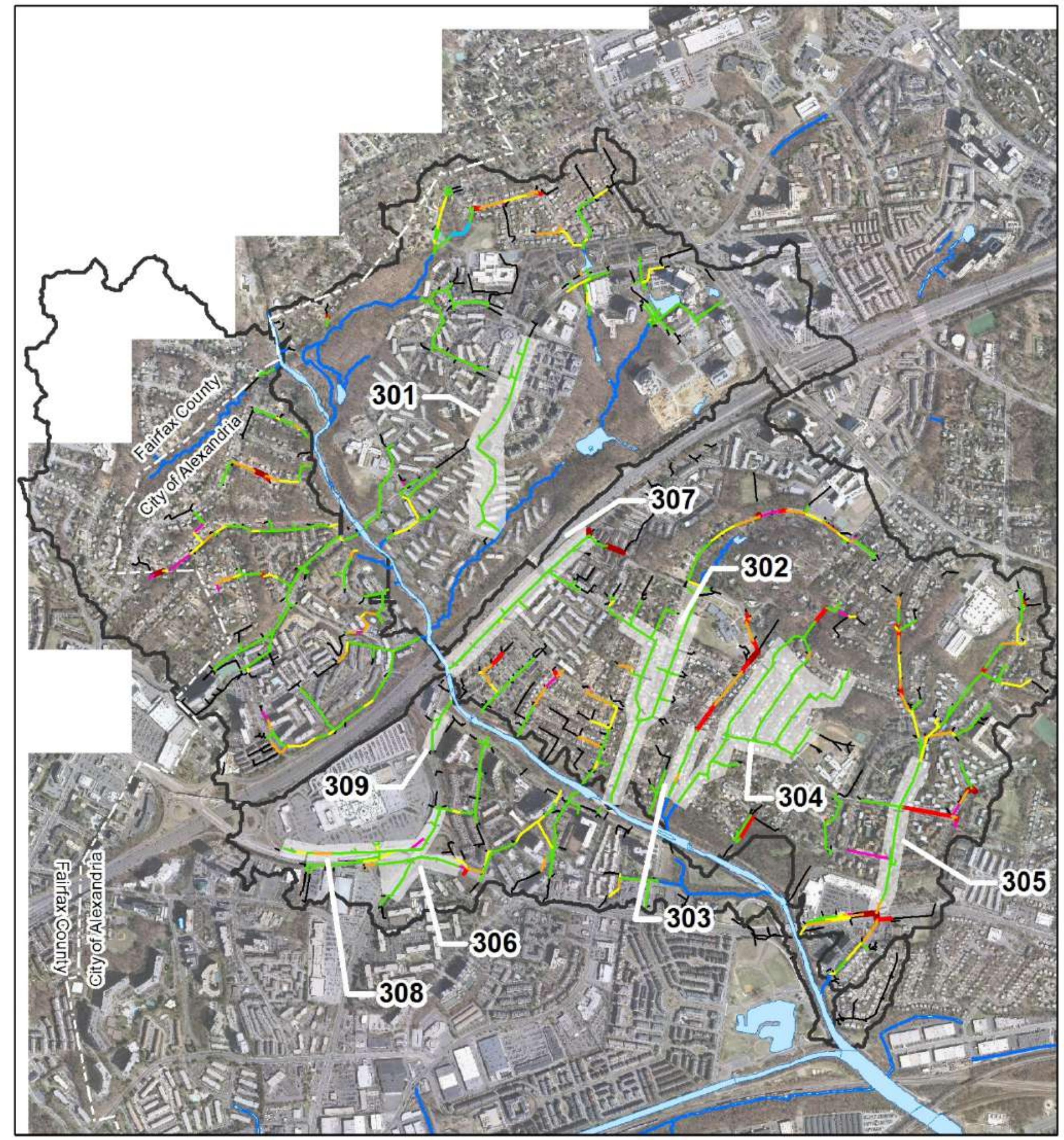
Existing Conditions Model Results
and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Holmes Run

0 750 1,500 3,000
Feet

N

CH2MHILL

FIGURE 4-2
Conveyance Solutions Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



Legend

Capacity
- Sufficient Capacity
- Surcharged
- Insufficient Freeboard

Flood Volume (cu. ft.)
- 0.01 - 1,000
- 1,000 - 10,000
- 10,000 - 405,000
- Not Analyzed (Private, disconnected, upstream of runoff input)

- Modeled Streams
- City of Alexandria Streams
- Water Bodies
- Watershed

Conveyance Solutions Model Results
and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Holmes Run

0 750 1,500 3,000
Feet

N

CH2MHILL

The conveyance solutions resolve most of the localized problems within the high-priority problem areas. In Holmes Run there is a limited amount of collection system downstream of the high-priority problems, therefore there is a limited potential to transfer the flooding downstream; however, the increased peak flow could have detrimental effects on the stream channel downstream. Table 4-2 summarizes the model results for the existing condition and the conveyance solutions models. Comparing the two results shows that the conveyance solutions reduce length of flooded pipes in the network by about 11 percent and reduce the overall flood volume by about 55 percent. The duration of surcharge and flooding are reduced by 40 and 64 percent, respectively.

TABLE 4-2
Summary of Existing Conditions and Conveyance Solution Model Results in Holmes Run
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Existing Capacity Results				Conveyance Solutions Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	46,462	47	-	-	67,584	69	-	-
Surcharged[a]	18,181	19	255	-	13,545	14	153	-
Insufficient Freeboard	15,282	16	-	-	9,817	10	-	-
Flooded	18,093	18	92	900,744	7,073	7	33	401,350

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Flooding outside of the high-priority problem areas was not addressed by the proposed solutions, therefore a summary of the modeling results within the high-priority problem areas is provided in Table 4-3. The average flood volume was reduced by 92 percent within the high-priority problem areas. A disadvantage of the conveyance solutions is that, while increasing pipe capacity reduces flooding within the problem area, it increases peak flows, which may increase flows in the downstream collection system and stream channels, and may increase or create flooding downstream. Peak flow was increased for all nine high-priority problem areas, though this increase was much higher in some problem areas, ranging from a 33 percent increase in Problem Area 302 to a 555 percent increase in Problem Area 309.

TABLE 4-3
Conveyance Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	Existing Conditions Model Results	Conveyance Solution Model Results	Percent Reduction	Existing Conditions Model Results	Conveyance Solution Model Results	Percent Increase
301	0.191	-	100	73	116	58
302	0.270	-	100	332	441	33
303	0.176	-	100	38	55	45
304	0.789	0.005	99	206	307	49
305	0.948	0.644	32	411	557	36
306	0.296	0.002	99	25	69	175

TABLE 4-3
Conveyance Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	**Existing Conditions Model Results**	**Conveyance Solution Model Results**	**Percent Reduction**	**Existing Conditions Model Results**	**Conveyance Solution Model Results**	**Percent Increase**
307	0.599	-	100	122	200	64
308	0.239	-	100	127	184	44
309	1.688	-	100	30	197	555
		Average	**92**			**118**

The approach of sizing the conveyance projects based on the unconstrained peak flow allowed all conveyance projects to be run in a single iteration. Since stormwater gravity main diameters were increased to convey the largest potential peak flow, the impact of increasing capacity upstream was incorporated into the sizing of any downstream conveyance solutions. However, evaluating all of the conveyance projects in a single model run has limitations. Because the problem areas are interconnected, modeling all solutions in a single run does not allow each solution to be viewed independently. In addition the Holmes Run model does not include the stream channels as part of the hydraulic network. An increase in peak flow may raise the HGL downstream of one problem area thus creating backwater conditions at outlets which affects other Problem Areas. Although the problem areas in Holmes Run are generally not within close proximity to one another, the second limitation should be kept in mind when reviewing the Conveyance results for Holmes Run.

4.2 Storage Solutions

Conventional SWM solutions considered in this study include detention facilities and ordinance changes. Because of the challenges of translating ordinance changes into hydrologic and hydraulic parameters, only storage solutions were modeled in xpswmm. Ordinance changes were reviewed during the Hooffs Run Task solutions analysis and are summarized in *Task 4: Problem and Solution Identification and Prioritization for Hooffs Run, Alexandria, Virginia* (CH2M HILL, 2016b)

The goal of storage solutions was to add storage to the stormwater drainage network to decrease peak flow and volume during the modeled rainfall event. Because of the urban nature of the study area, it was assumed that to provide a sufficient storage volume, detention facilities would have to be belowgrade vaults. Several constraints guided the siting of potential storage solutions, including:

- Depth of storage facility should not exceed 10 feet to minimize excavation costs.
- Storage will be dewatered by gravity to a manhole less than 1,000 feet downstream to eliminate pumping costs.
- Minimum storage depth should be 3 feet, measured from the storage inlet to the storage outlet.
- Only surcharged flow will be sent to storage.

The first step in developing storage solutions was to identify open space that may be available for subsurface storage vaults with preference for City-owned property. This primarily includes parking lots, green space (for example, parks, school yards, playing fields, church yards), and grassed medians or boulevards. These opportunities were identified using aerial imagery and were deemed feasible using drainage network data (gravity main locations and inverts) and topographic data. Only Problem Area 302 has an area that meets the constraints described above; no storage opportunities were identified for Problem Areas 301, or 303-309. A map showing the location in 302 is provided on Figure 4-3, and Table 4-4 identifies the storage depth, area, and volume. Additional details on the storage solution location are provided in Appendix B.

FIGURE 4-3
Storage Solution Locations and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

FIGURE 4-4
Storage Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

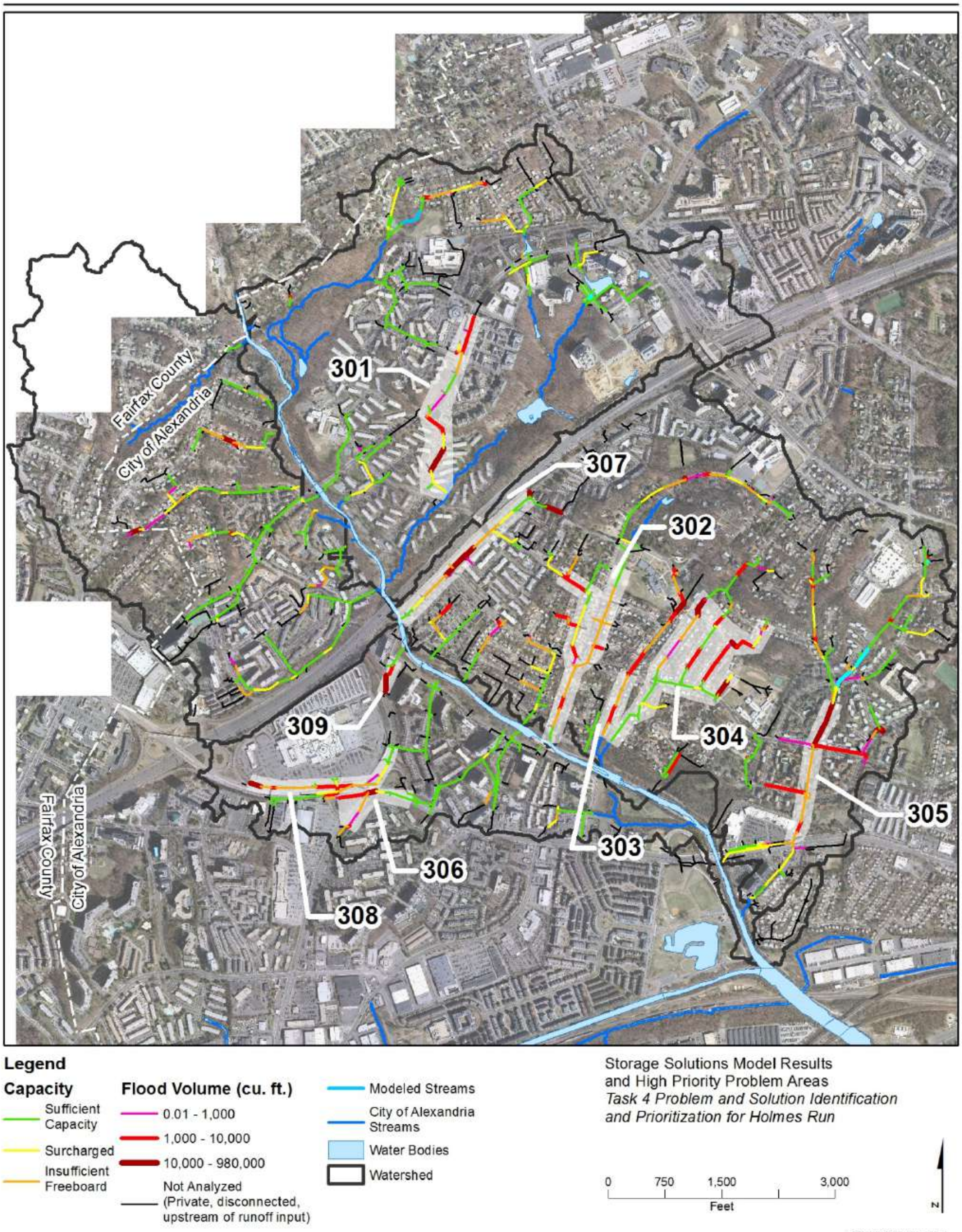


TABLE 4-4
Storage Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area ID	Storage ID(s)	Max Depth (ft)	Total Storage Area (ft^2)	Volume (ft^3)
302	Node 5359	10	1,351	13,513

A map of the results of the storage solution model run is provided on Figure 4-4, and a summary of the results is provided in Table 4-5.

TABLE 4-5
Summary of Storage Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Existing Conditions Results				Storage Solutions Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	46,462	47	-	-	48,739	50	-	-
Surcharged[a]	18,181	19	255	-	15,942	16	260	-
Insufficient Freeboard	15,282	16	-	-	16,580	17	-	-
Flooded	18,093	18	92	900,744	16,758	17	94	978,096

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Because a storage solution could only be identified for one location in Holmes Run, the storage solutions did not impact the total volume of flooding in the watershed. A summary of the modeling results within high-priority problem area 302 is provided in Table 4-6.

TABLE 4-6
Storage Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	Existing Conditions Model Results	Storage Solution Model Results	Percent Reduction	Existing Conditions Model Results	Storage Solution Model Results	Percent Reduction
302	0.270	0.090	33	331	331	0

4.3 Green Infrastructure Solutions

The goal of GI solutions was to reduce the peak runoff rate and runoff volume directed to the storm drainage system by converting impervious surfaces to pervious surfaces. This is accomplished in the field by redirecting runoff from impervious surfaces to GI facilities that detain and infiltrate runoff during rainfall events. Three levels of GI—low, medium, and high—were evaluated in this analysis. In the model, GI was evaluated by reducing the impervious cover in model subcatchments by 10 percent, 30 percent, and 50 percent to represent the low, medium, and high levels of implementation, respectively.

Several GI technologies were considered feasible within the City of Alexandria including:

- **Bioretention/ Planters** – planted depression or constructed box with vegetation that typically receives runoff from roadways or rooftop; includes vegetation and soil media over an underdrain and filtration fabric; The City does not typically encourage infiltration, therefore rain gardens, which typically do not have an underdrain, are not encouraged.
- **Cisterns** – a tank for storing water, typically connected to a roof drain, which can be either above or below ground; water from a cistern is typically reused or slowly infiltrated into the soil rather than discharged to a storm sewer
- **Green/Blue Roofs** - a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane (green roof) or a roof that is capable of storing and then slowly releasing rainwater (blue roof)
- **Porous Pavement** - paving surfaces designed to allow stormwater infiltration; may or may not include underground storage component
- **Surface Storage** – retrofit of inlets and catch basins to include flow regulators on streets with standard curb and gutter system so that stormwater can be stored within the roadway and slowly released back into the storm sewer system
- **Amended Soils** – altering soils to improve water retention, permeability, infiltration, drainage, aeration, and/or structure

These technologies were grouped into GI programs based on the landuses where they could be applied: A program combines a set of technologies into an implementation strategy for different types of sites and land use categories. Programs being considered are described below.

- **Green Streets/Alleys** – includes bioretention/planters and porous pavement combined along the public right-of-way between buildings and roadways; can include parking lane and curb cuts
- **Green Roofs** – includes green/blue roofs, sometimes in combination with cisterns
- **Green Schools** – use of school properties to implement one-to-many GI management strategies, including bioretention/planters, cisterns, green/blue roofs, and porous pavement
- **Green Parking** – bioretention/planters and porous pavement in parking lots
- **Green Buildings** – use of bioretention/planters, cisterns, and/or downspout disconnection on public or private buildings
- **Blue Streets** – short term surface storage on streets with relatively flat slopes and standard curb and gutter systems
- **Open Spaces** – use of open spaces to store and/or infiltrate stormwater with the use of a combination of detention, amended soils, bioretention/planters, and/or porous pavement; may also include stream daylighting where appropriate

Six GI concepts were developed for the Holmes Run Watershed. These concepts, which are described in greater detail in Appendix C, demonstrate the applicability of GI technologies in the City of Alexandria.

A drainage area for each high-priority area was identified using the model's hydrologic subcatchments. Because the drainage area includes all model subcatchments upstream of the problem area, where there are problem areas upstream of one another, drainage areas overlap. A map of these drainage areas and problem area locations is provided on Figure 4-5, and Table 4-7 summarizes the drainage area, existing impervious area, and impervious area for each level of GI implementation.

FIGURE 4-5
Green Infrastructure Drainage Areas and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

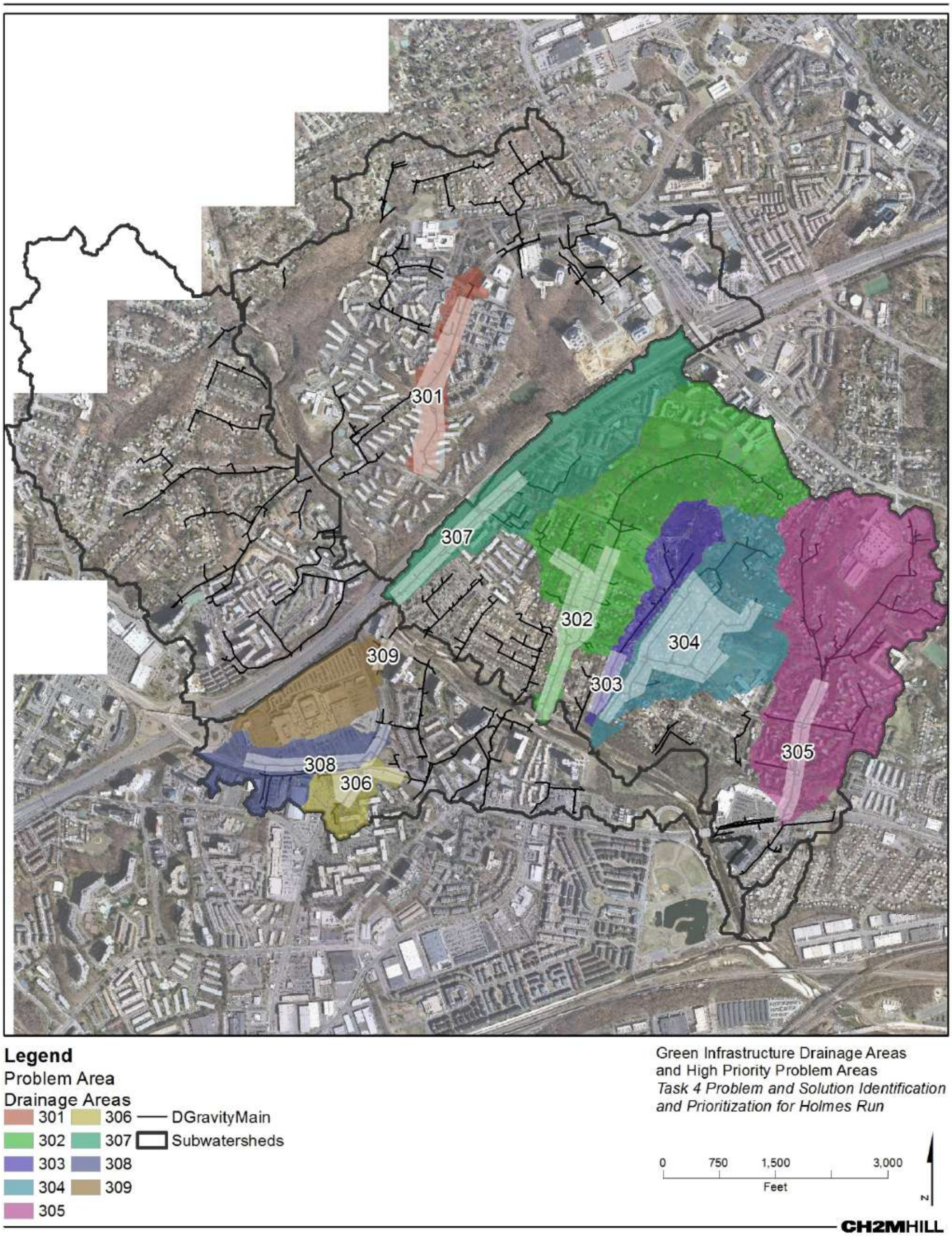


TABLE 4-7
Green Infrastructure Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area ID	Drainage Area (acres)	Existing Impervious Area (acres)	GI Solution Impervious Area (acres)		
			Low Implementation	Medium Implementation	High Implementation
301	24.2	13.2	12.4	10.8	9.3
302	139.9	44.7	41.9	36.1	30.4
303	28.8	9.8	9.5	8.9	8.4
304	90.6	24.5	23.1	20.2	17.4
305	161.7	69.0	63.5	52.6	41.6
306	17.4	10.6	9.7	7.9	6.1
307	79.2	40.5	40.4	40.2	40.1
308	34.9	26.7	24.1	19.0	13.9
309	37.0	31.9	31.7	31.4	31.1

Maps of the results of the low, medium, and high GI solutions are provided on Figures 4-6 through 4-8, and a summary of the model results is provided in Table 4-8.

FIGURE 4-6
Low-implementation Green Infrastructure Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

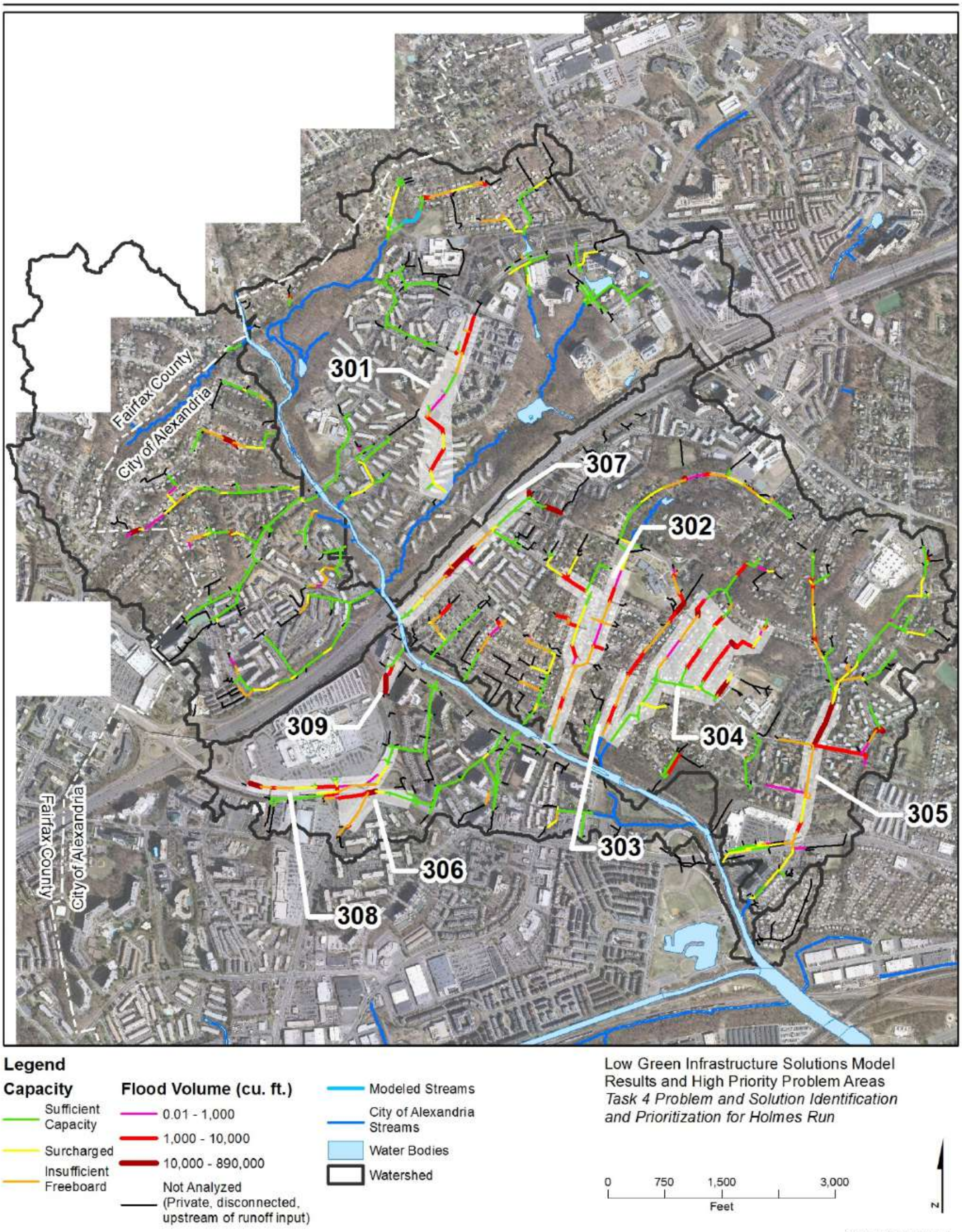


FIGURE 4-7
Medium-implementation Green Infrastructure Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

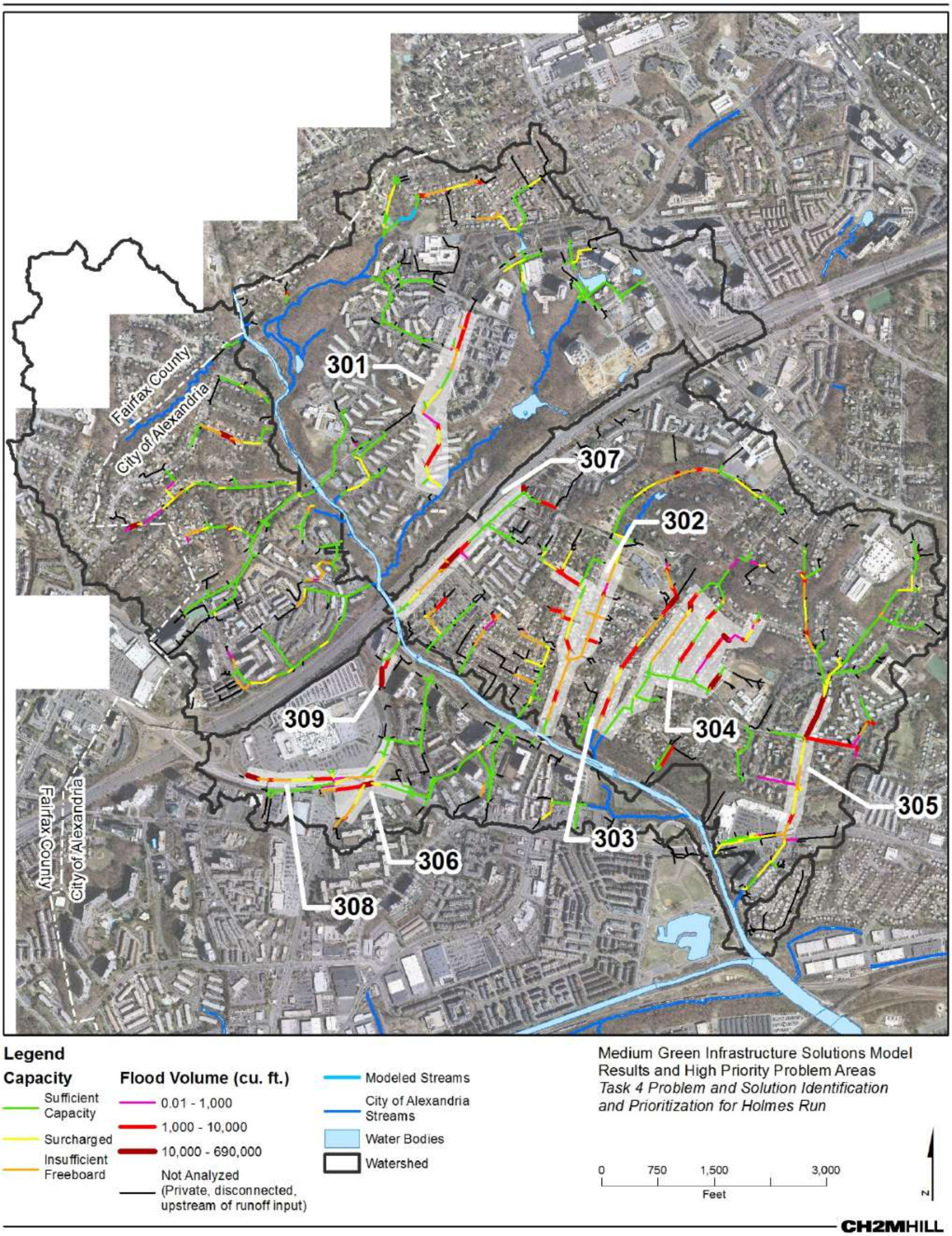
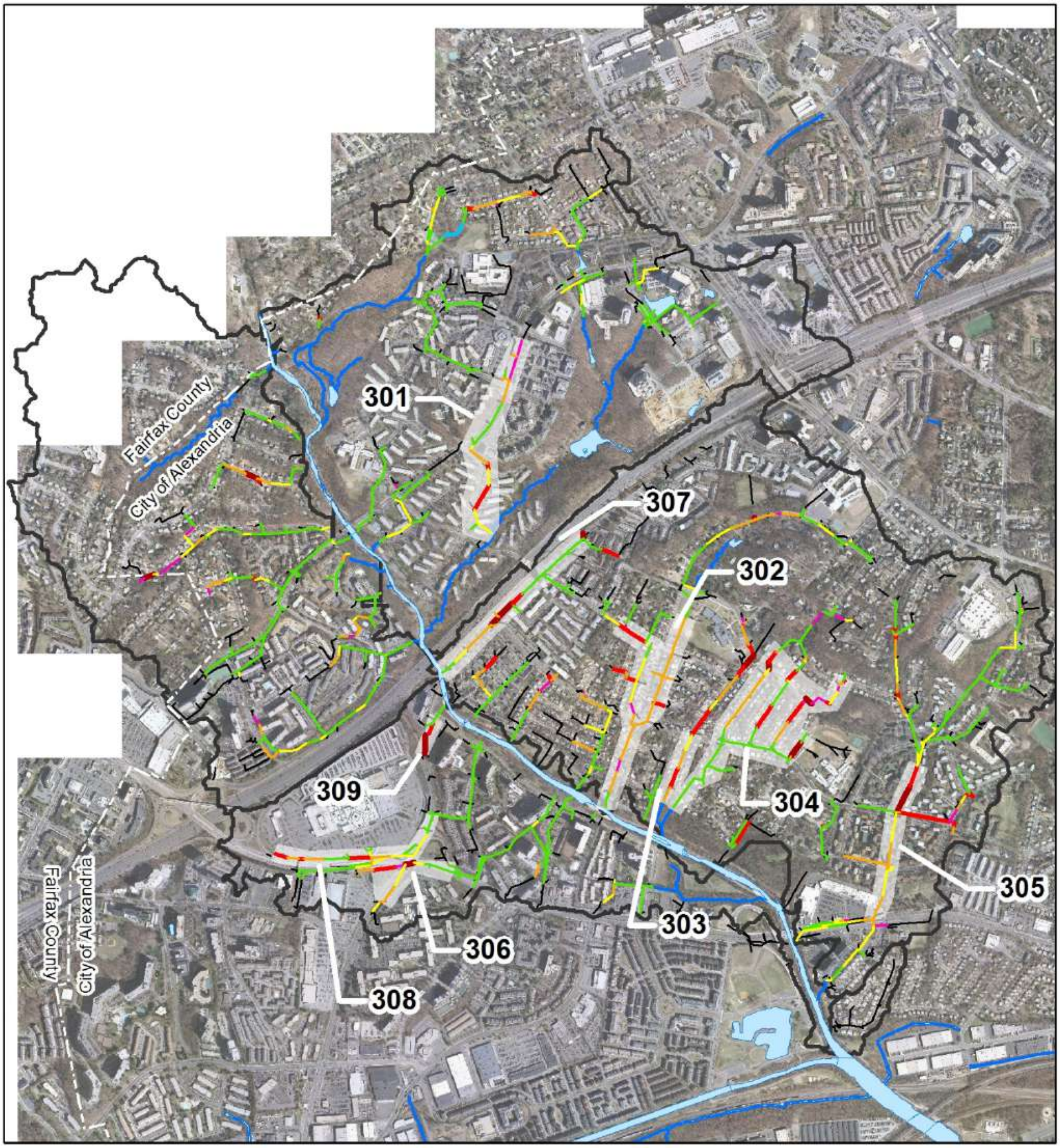


FIGURE 4-8
High-implementation Green Infrastructure Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



Legend

Capacity
- Sufficient Capacity
- Surcharged
- Insufficient Freeboard

Flood Volume (cu. ft.)
- 0.01 - 1,000
- 1,000 - 10,000
- 10,000 - 490,000
- Not Analyzed (Private, disconnected, upstream of runoff input)

- Modeled Streams
- City of Alexandria Streams
- Water Bodies
- Watershed

High Green Infrastructure Solutions Model Results and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Holmes Run

0 750 1,500 3,000
Feet

N

CH2MHILL

TABLE 4-8
Summary of Existing Conditions Capacity and Green Infrastructure Implementation Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Low GI Implementation Results				**Medium GI Implementation Results**				**High GI Implementation Results**			
	Conduit Length (LF)	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**	**Conduit Length (LF)**	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**	**Conduit Length (LF)**	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**
Sufficient Capacity	49,527	51	-	-	52,763	54	-	-	54,724	56	-	-
Surcharged[a]	16,365	17	250	-	16,694	17	229	-	15,925	16	207	-
Insufficient Freeboard	15,816	16	-	-	14,301	15	-	-	15,274	16	-	-
Flooded	16,311	17	89	889,711	14,260	15	76	684,412	12,096	12	61	488,661

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Overall, model results indicate that GI may be effective at reducing flood volumes and durations, more so at higher levels of implementation. A 50 percent reduction in impervious area reduces length of flooded pipes in the network by about 6 percent and reduces total flood volume by about 46 percent.

Flooding outside of the high-priority problem areas was not addressed by the proposed solutions, therefore results within each high-priority problem area are shown in Tables 4-9 and 4-10. On average, the flood volume was reduced by 13 percent in high-priority problem areas by the low GI implementation, 35 percent by the medium GI implementation, and about 57 percent by the high GI implementation. Peak flow results were less dramatic, with the low GI implementation reducing peak flow by about 0.8 percent on average, medium GI implementation reducing peak flow by about 2.3 percent, and high GI implementation reducing peak flow by 4.4 percent.

TABLE 4-9
Green Infrastructure Solutions Flood Volume Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

		Low GI Implementation		Medium GI Implementation		High GI Implementation	
Problem Area ID	**Existing Conditions Flood Volume (MG)**	**Solution Flood Volume (MG)**	**Percent Reduction**	**Solution Flood Volume (MG)**	**Percent Reduction**	**Solution Flood Volume (MG)**	**Percent Reduction**
301	0.191	0.166	13	0.075	39	0.128	67
302	0.270	0.223	17	0.133	49	0.210	78
303	0.176	0.136	22	0.069	39	0.098	55
304	0.789	0.685	13	0.203	26	0.307	39
305	0.948	0.845	11	0.392	41	0.642	68
306	0.296	0.282	5	0.056	19	0.103	35
307	0.599	0.426	29	0.261	43	0.353	59
308	0.239	0.237	1	0.077	32	0.150	63
309	1.688	1.566	7	0.435	26	0.771	46
		Average	**13**		**35**		**57**

TABLE 4-10
Gi Solutions Peak Flow Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

		Low GI Implementation		Medium GI Implementation		High GI Implementation	
Problem Area ID	**Existing Conditions Peak Flow (cfs)**	**Solution Peak Flow (cfs)**	**Percent Reduction**	**Solution Peak Flow (cfs)**	**Percent Reduction**	**Solution Peak Flow (cfs)**	**Percent Reduction**
301	73	73	1.0	71	3.2	69	5.5
302	332	331	0.3	328	1.1	325	1.9
303	38	38	0.5	38	0.9	37	1.4
304	206	201	2.4	194	6.0	187	9.6
305	411	409	0.5	404	1.6	401	2.3

TABLE 4-10
Gi Solutions Peak Flow Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

306	25	25	0.2	25	0.7	25	1.4
307	122	121	0.9	118	2.9	116	5.3
308	127	127	0.3	125	1.8	118	7.2
309	30	30	0.9	29	2.7	29	4.6
		Average	**0.8**		**2.3**		**4.4**

SECTION 5
Alternatives Analysis and Prioritization

The goal of alternatives analysis and prioritization was to evaluate the cost and performance of the various solution approaches/technologies and develop watershed-wide alternatives aimed at resolving capacity related problems in the Holmes Run Watershed. The solution identification process resulted in 37 unique projects for the nine high-priority problem areas in the Holmes Run Watershed. The alternatives analysis and prioritization was performed after completing the solution modeling for the high-priority problem areas. The following section describes the results of the alternatives analysis and prioritization.

5.1 Problem Area Benefit Analysis

The 37 solutions for the 9 high-priority problem areas were scored for the eight solution evaluation criteria:

- Urban drainage/flooding
- Environmental compliance
- Ecocity goals/sustainability
- Social benefits
- Integrated asset management
- City-wide maintenance implications
- Constructability
- Public acceptability

After completing preliminary scoring of projects in Hooffs Run, City staff reviewed prioritization results to ensure the objectives of the analysis were being met. This review resulted in a minimum flood reduction threshold of 22 percent for all projects. If projects did not meet this minimum threshold, they were not included in the prioritization, though the scoring and costing data were maintained for documentation. Of the 37 solutions, 8 did not meet the minimum flood reduction threshold, leaving 29 projects.

Figures 5-1 and 5-2 show bar charts of the total benefit scores for each of these 29 projects. The horizontal axis has the project name, which is a combination of the problem area number and the technology/solution approach type. For example, CONV-301 is the conveyance solution for problem area 301; STOR-301 is the storage solution; and LGI-301, MGI-301, and HGI-301 are the low, medium, and high GI implementations, respectively. The charts show all solutions included in the prioritization (that is, all solutions providing at least 22 percent reduction in flooding) by problem area in ascending order from left to right.

A full table of the scoring and alternatives analysis results is included in Appendix D.

FIGURE 5-1
Total Benefit Score Chart for High-priority Problem Areas 301 through 304
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

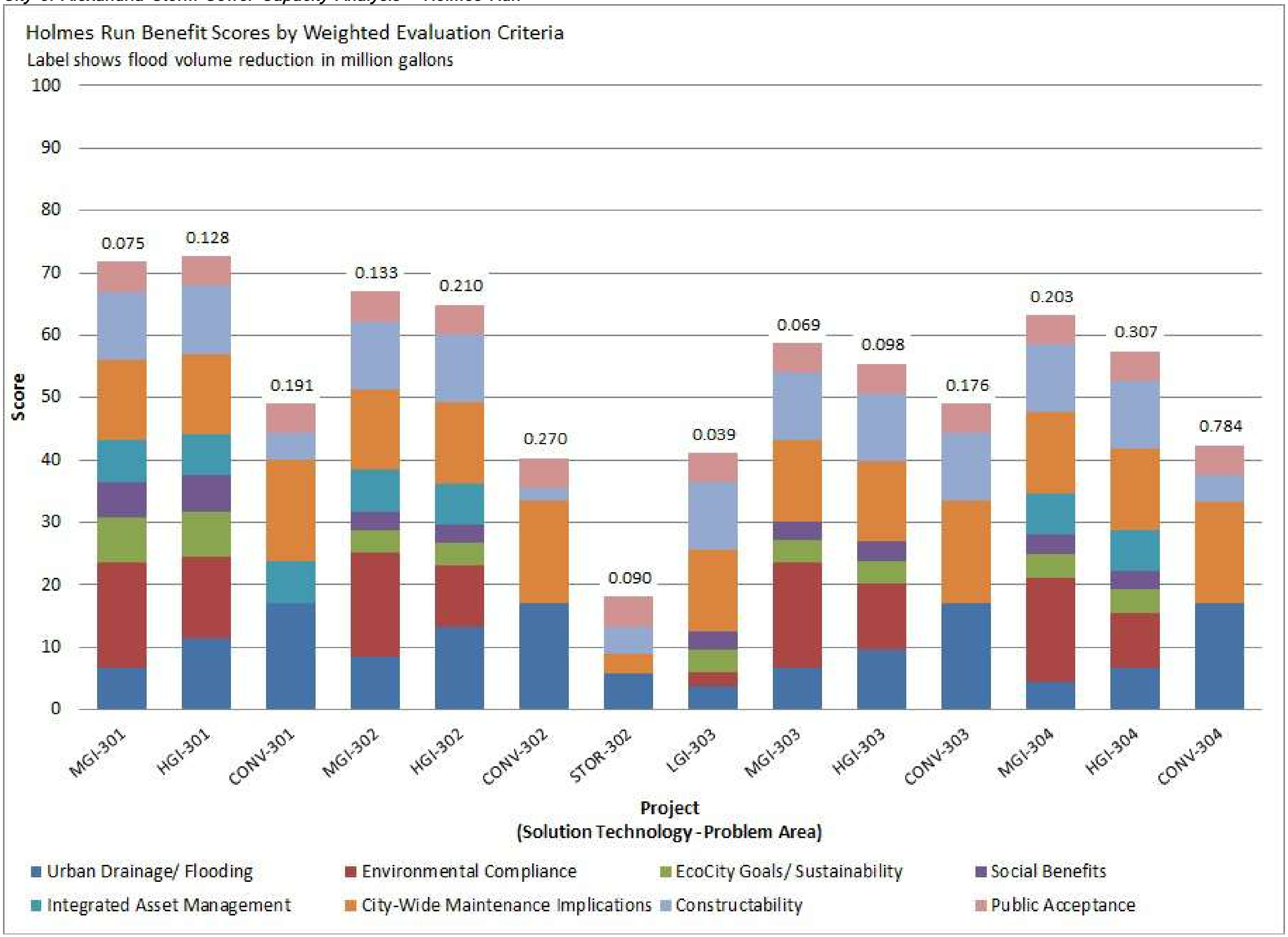
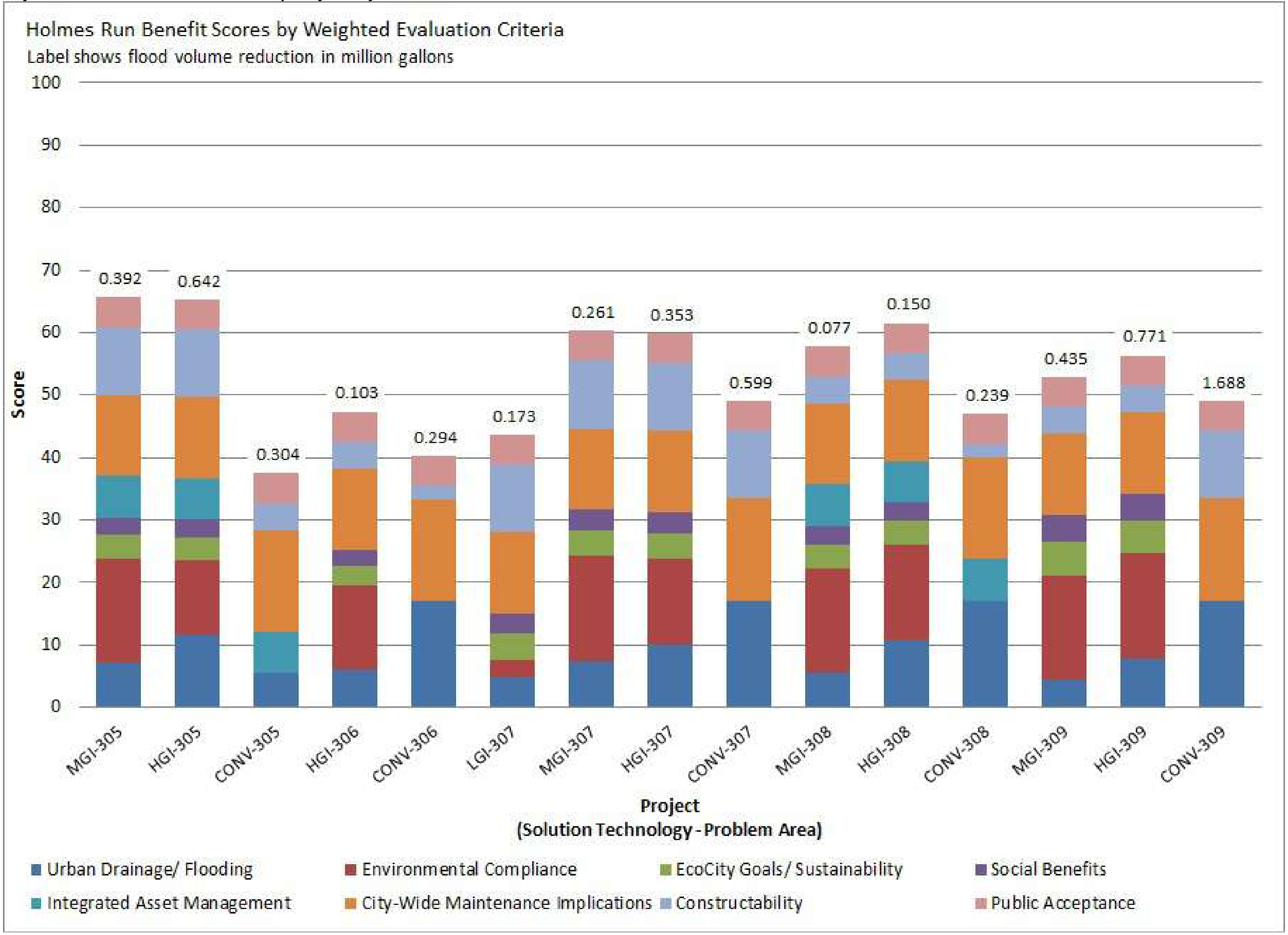


FIGURE 5-2
Total Benefit Score Chart for High-priority Problem Areas 305 through 309
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



5.2 Problem Area Solution Costs

Planning-level capital costs, which include construction as well as engineering and design and contingency, were developed for each of the 37 solutions. The basis of the costs information for each technology is provided in Appendix E.The basic unit costs used for costing the various projects were the same across all City infrastructure projects. Three levels of GI implementation were evaluated for this project:

- High Implementation – Manage 50% of total impervious area in the watershed
- Medium Implementation – Manage 30% of total impervious area in the watershed
- Low Implementation – Manage 10% of total impervious area in the watershed

The unit cost of implementing GI at the various implementation levels is driven by the availability of GI opportunity areas. Since the GI opportunity areas varied across watersheds, the cost of implementation of the various levels of GI also varies across watersheds. Table 5-1 provides the construction cost assumptions for the low, medium, and high implementation levels of GI in Holmes Run watershed based on implementing GI across the whole watershed.

TABLE 5-1
Green Infrastructure Construction Costs
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Area Managed			
GI Level	**%**	**Ac**	**Cost Per Acre Managed**	**Construction Cost**
Low GI	10	68.9	$46,720	$3,219,012
Medium GI	30	206.7	$78,544	$16,235,049
High GI	50	344.5	$86,686	$29,863,372

Table 5-2 provides the capital cost in millions of dollars for all 37 solutions. Projects that do not meet the minimum threshold for flood reduction ar shown in ***bold italics***

TABLE 5-2
Capital Costs for High-priority Problem Area Solutions
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area	Conveyance	Storage	Low GI	Medium GI	High GI
301	$1.115	N/A	***$0.086***	$0.435	$0.800
302	$3.330	$0.225	***$0.293***	$1.475	$2.714
303	$0.501	N/A	$0.064	$0.322	$0.593
304	$2.810	N/A	***$0.160***	$0.808	$1.485
305	$2.675	N/A	***$0.451***	$2.276	$4.187
306	$0.662	N/A	***$0.069***	***$0.349***	$0.643
307	$2.698	N/A	$0.265	$1.335	$2.456
308	$1.401	N/A	***$0.174***	$0.879	$1.618
309	$0.250	N/A	***$0.209***	$1.052	$1.935

Note: Costs shown in ***bold italics*** are for projects that do not meet the 22 percent minimum flood reduction threshold set by the City.
Costs are in millions of dollars.

5.3 Problem Area Benefit/Cost Results

The benefit/cost score is the ratio of the total benefit divided by the total capital cost in millions of dollars. This metric indicates the cost efficiency of a project and can help direct resources to the projects that will provide the greatest benefit for the lowest cost. Cost benefit results are presented in Figures 5-3 and 5-4. The charts show only projects meeting the 22 percent minimum flood reduction threshold and are presented by problem area in ascending order from left to right on the horizontal access.

The benefit/cost score is shown as a bar chart in blue. Additionally, the cost per gallon of flood reduction is included as a line on a secondary axis. This metric provides an alternative cost-based method for ranking projects. It is important to remember that the best projects will have a high benefit/cost score but a low cost per gallon of flood reduction.

FIGURE 5-3
Benefit/Cost Chart for High-priority Problem Areas 301 through 304
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

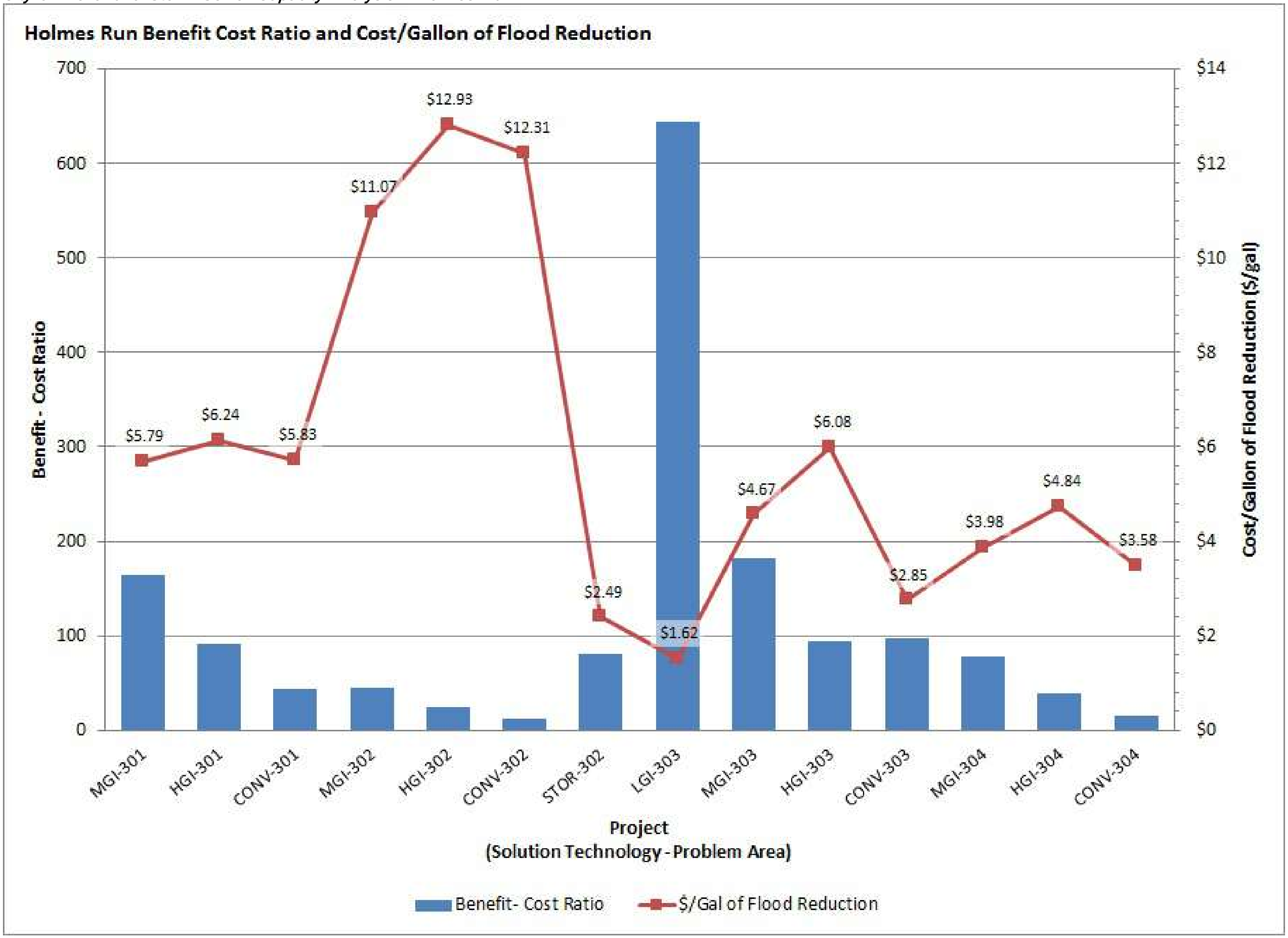
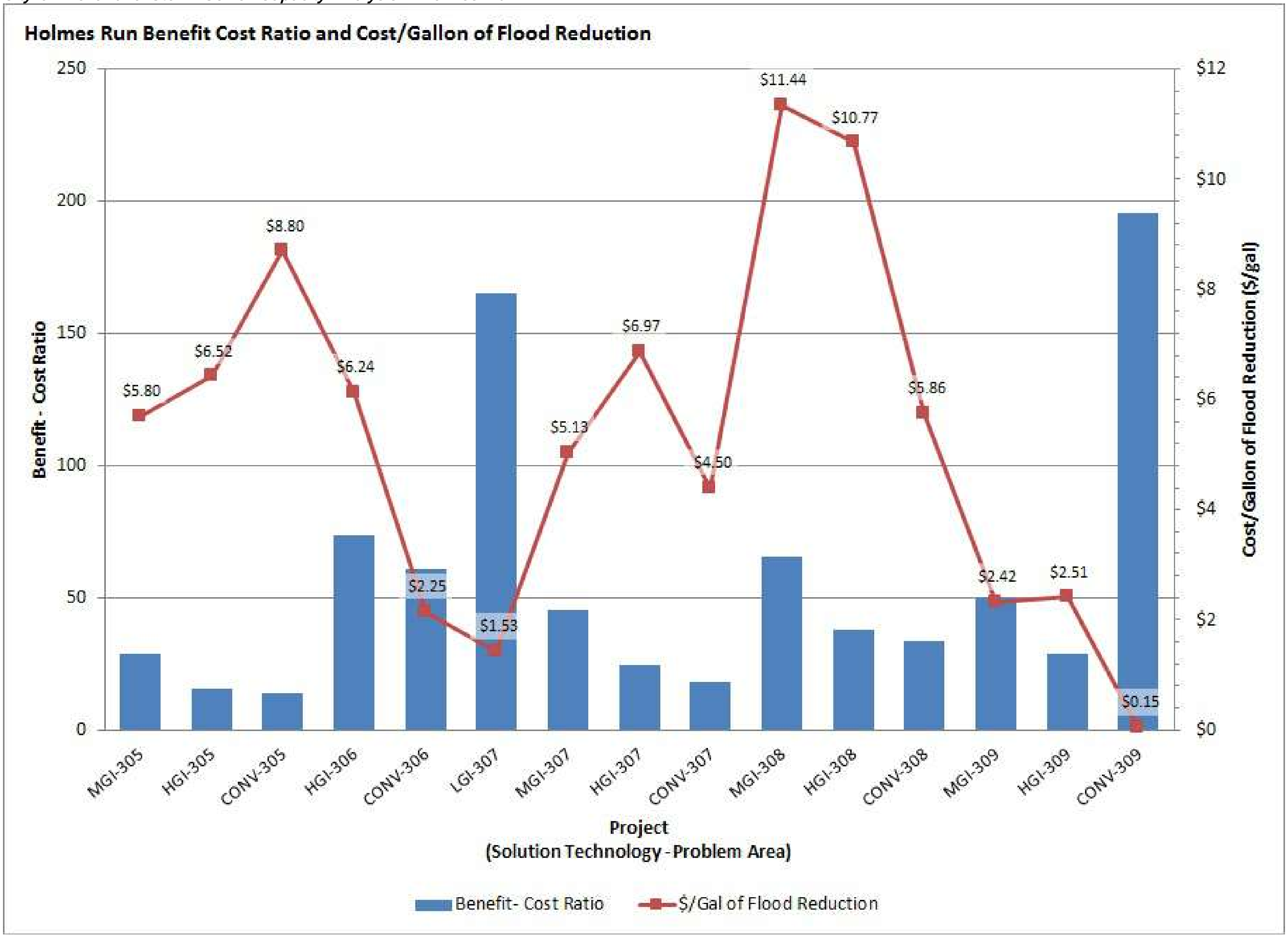


FIGURE 5-4
Benefit/Cost Chart for High-priority Problem Areas 305 through 309
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



5.4 Watershed-wide Alternatives

Three watershed-wide alternatives were developed for Holmes Run. Each watershed-wide alternative was aimed at resolving capacity-related issues while also meeting a second goal: including maximizing cost-efficiency or benefit cost or targeting the highest-priority problems. The three alternatives examined include:

- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to resolve the highest-priority problem areas

Projects were selected for each of the watershed-wide alternatives based on the five individual technology-specific modeling results (Conveyance, Storage, and Low GI, Medium GI, and High GI implementation). A new model including the selected projects was run for each alternative. Results for the watershed-wide model runs are presented in section 5.4.4 and 5.4.5.

5.4.1 Alternative 1: Cost Efficiency

The first alternative focused on providing the best cost efficiency in each problem area. After removing projects that did not meet the minimum flood reduction threshold of 22 percent, the remaining projects were ranked by cost-per-gallon of flood reduction within each problem area in ascending order. The highest-ranked project, which was the project with the lowest cost-per-gallon of flood reduction, was selected for each problem area. Table 5-3 shows the selected project for each problem area. This alternative consisted primarily of conveyance solutions and GI projects and one storage solution. Model results are summarized in Table 5-7 and presented on Figure 5-5.

TABLE 5-3
Selected Projects for Watershed-wide Alternative 1: Cost Efficiency
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
301	Medium GI	MGI-301	$0.435	164.9	0.075	39	$5.79
302	Storage	STOR-302	$0.225	80.4	0.090	33	$2.49
303	Low GI	LGI-303	$0.064	645.0	0.039	22	$1.62
304	Conveyance	CONV-304	$2.810	15.1	0.784	99	$3.58
305	Medium GI	MGI-305	$2.276	28.8	0.392	41	$5.80
306	Conveyance	CONV-306	$0.662	60.8	0.294	99	$2.25
307	Low GI	LGI-307	$0.265	165.0	0.173	29	$1.53
308	Conveyance	CONV-308	$1.401	33.5	0.239	100	$5.86
309	Conveyance	CONV-309	$0.250	195.7	1.688	100	$0.15
		Total	**$8.387**		**4.20**	**81[a]**	**$2.00**

Notes:
Results presented in this table are based on separate technology based model runs (Conveyance, Storage, and Low, Med, and High GI)
[a] Existing flood volume for Problem Areas 301 through 309 is 5.20 MG.
GI = GI

5.4.2 Alternative 2: Benefit/Cost

The second alternative focused on providing the best benefit/cost in each problem area. After removing projects that did not meet the minimum flood reduction threshold of 22 percent, the remaining projects were ranked by benefit/cost in descending order. The highest-ranked project in each of the nine problem areas, which was the project with the highest benefit/cost score, was selected. Table 5-4 shows the selected project for each problem area. This alternative consisted primarily of medium and high GI projects along with a conveyance and a storage project. Model results are summarized in Table 5-7 and presented on Figure 5-6.

TABLE 5-4
Selected Projects for Watershed-wide Alternative 2: Benefit/Cost
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
301	Medium GI	MGI-301	$0.435	164.9	0.075	39	$5.79
302	Storage	STOR-302	$0.225	80.4	0.090	33	$2.49
303	Low GI	LGI-303	$0.064	645.0	0.039	22	$1.62
304	Medium GI	MGI-304	$0.808	78.3	0.203	26	$3.98
305	Medium GI	MGI-305	$2.276	28.8	0.392	41	$5.80
306	High GI	HGI-306	$0.643	73.7	0.103	35	$6.24
307	Low GI	LGI-307	$0.265	165.0	0.173	29	$1.53
308	Medium GI	MGI-308	$0.879	65.7	0.077	32	$11.44
309	Conveyance	CONV-309	$0.250	195.7	1.688	100	$0.15
		Total	**$5.844**		**2.841**[a]	**55**	**$2.06**

Notes:
Results presented in this table are based on separate technology based model runs (Conveyance, Storage, and Low, Med, and High GI)
[a] Existing flood volume for Problem Areas 301 through 309 is 5.20 MG.
GI = green infrastructure

5.4.3 Alternative 3: Highest-priority Problems

The third alternative focused on resolving the highest-priority problems by combining multiple solutions within a problem area. The minimum threshold of 22 percent on flood reduction was removed because the goal was to eliminate as much flooding as possible from the problem area. In some cases, the combination of a storage or conveyance project that offered substantial flood reduction combined with a project such as low GI, which offered less than 22 percent flood reduction, could eliminate flooding within a problem area. The best combination of solutions in terms of cost efficiency, benefit/cost, and overall flood reduction were compiled to attempt to resolve the worst problem areas. Because 9 project were recommended in Alternatives 1 and 2 (one per project area), 9 projects were selected for Alternative 3 to keep all three alternatives relatively consistent in scale. A total of 9 projects were selected for Problem Areas 1 through 9. Table 5-5 shows the selected project for each problem area. Model results are summarized in Table 5-7 and presented in Figure 5-7.

TABLE 5-5
Selected Projects for Watershed-wide Alternative 3: Highest-priority Problems
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
301	Conveyance	CONV-301	$1.115	44.1	0.191	100	$5.83
302	Conveyance	CONV-302	$3.330	12.1	0.270	100	12.31
303	Conveyance	CONV-303	$0.501	97.7	0.176	100	$2.85
304	Conveyance	CONV-304	$2.810	15.1	0.784	99	$3.58
305	High GI	HGI-305	$4.187	15.5	0.642	68	$6.52
305	Conveyance	CONV-305	$2.675	14.0	0.304	32	$8.80
307	Conveyance	CONV-307	$2.698	18.2	0.599	100	$4.50
308	Conveyance	CONV-308	$1.401	33.5	0.239	100	$5.86
309	Conveyance	CONV-309	$0.250	195.7	1.688	100	$0.15
		Total	**$18.967**		**4.894**	**100[a]**	**$3.88**

Notes:
Results presented in this table are based on separate technology based model runs (Conveyance, Storage, and Low, Med, and High GI)
[a] Existing flood volume for Problem Areas 301 through 309, excluding Problem Area 306 is 4.90 MG.
GI = green infrastructure

5.4.4 Modeling Results

Table 5-6 provides a summary of the hydraulic model results for the three watershed-wide alternatives. Alternative 3, which focuses on resolving the highest priority problems, provides the greatest reduction of flooding in the system in terms of total length of pipe experiencing flooding and also minimizes the duration of surcharging and flooding. However, Alternative 1 minimizes the total volume of flooding in the system overall. Maps comparing the model results are presented on Figures 5-5 through 5-7.

Each of the alternatives analyzed is still leaving areas with flooding (as shown by red lines on the maps), largely because those areas are outside the boundaries of the “high-priority problem areas”. These areas were not addressed by solutions because they were either flooding at isolated structures, or did not score high based on the problem area scoring criteria.

FIGURE 5-5
Alternative 1: Cost-efficiency Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

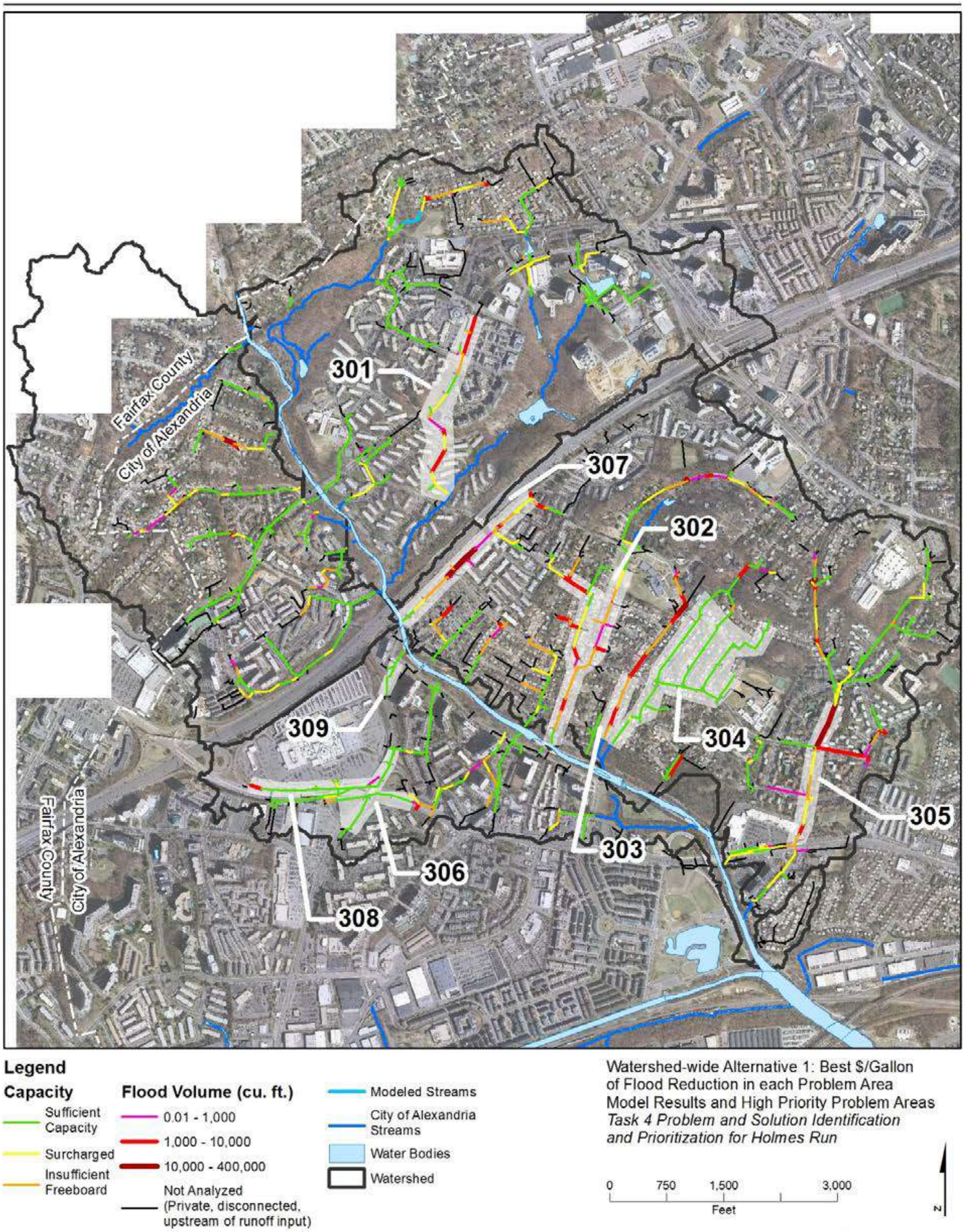


FIGURE 5-6
Alternative 2: Best Benefit/Cost Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

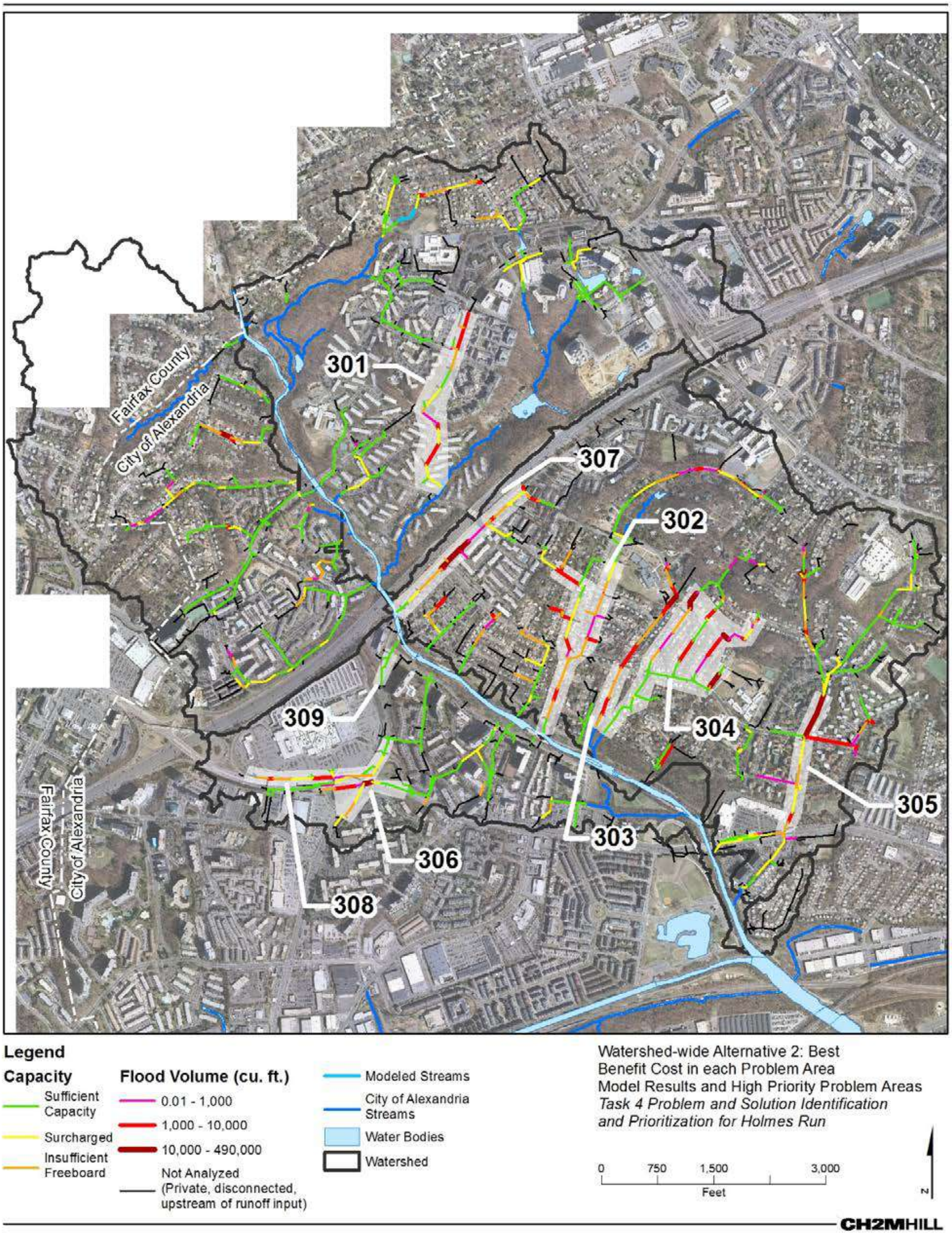
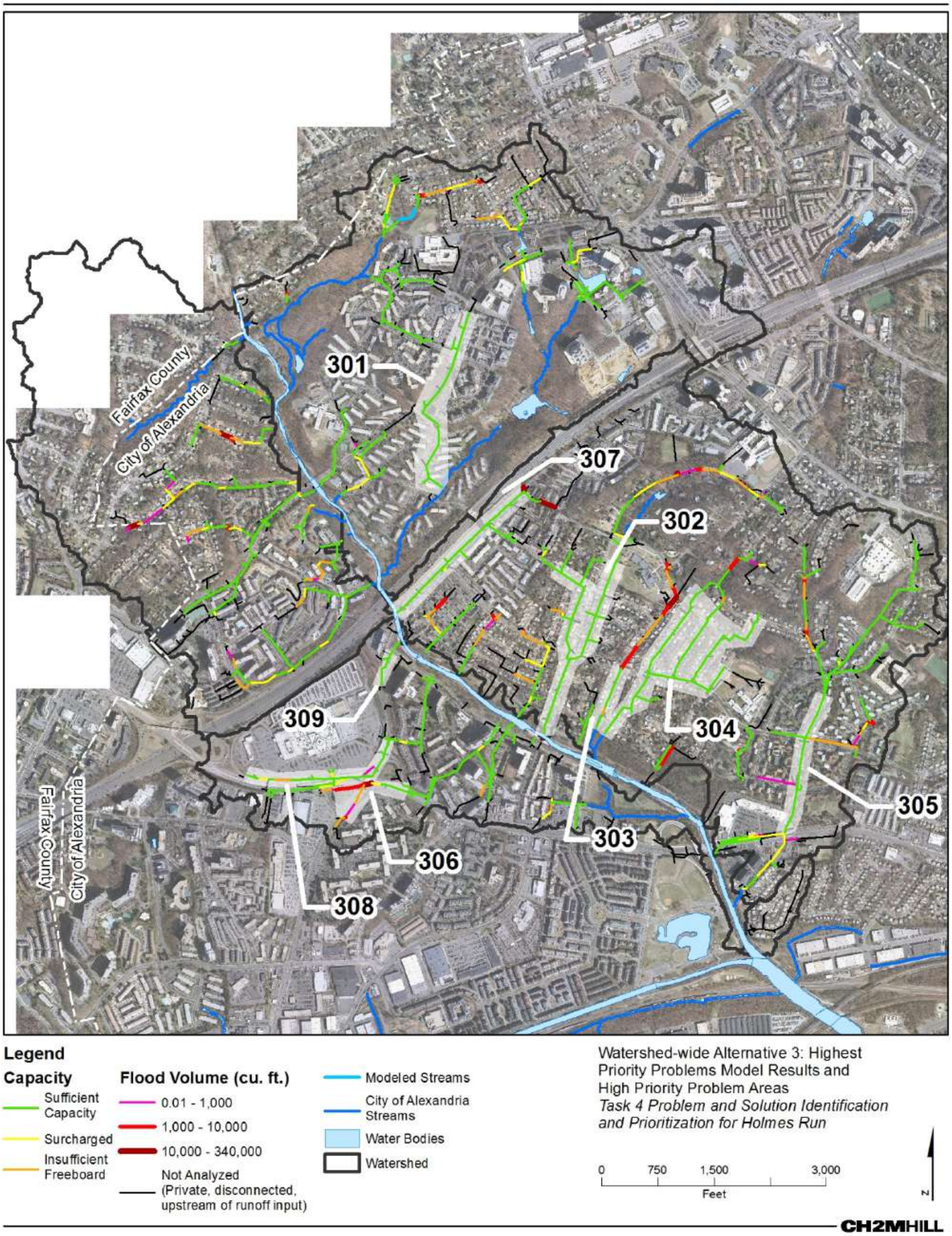


FIGURE 5-7
Alternative 3: Highest-Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



5.4.5 Scoring and Prioritization Results

The results for each alternative generally reflect the objective of that particular alternative. A summary of the results is provided in Table 5-7 below. A model was run for each of the alternatives, so the alternative-specific results presented in Table 5-7 may differ slightly from the results generated from the technology-specific model runs used to evaluate each solution type.

Alternative 1 was built on the objective of providing the best cost efficiency in each of the nine high-priority problem areas. This resulted in a higher total capital cost than Alternative 2, but reduced the flooding in the nine high-priority problem areas by about one million gallons over Alternative 2. Alternative 2 focused on the solutions that had the highest benefit/cost ratio in each of the nine high-priority problem areas. This focus resulted in the highest benefit/cost ratio and the lowest cost per million gallons of flood reduction of the three alternatives. Conversely, Alternative 2 resulted in the smallest flood volume reduction of the three alternatives. Alternative 3, which focused on providing the greatest overall relief within the nine high-priority problem areas, resulted in the highest overall benefit score and the greatest total flood reduction but at the highest cost. Therefore Alternative 2 is the recommended alternative as most cost-effective project, both from flood reduction and benefit/cost perspective.

TABLE 5-7
Watershed-wide Alternatives Scoring and Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Alternative 1 - Best Cost Efficiency	Alternative 2 - Best Benefit/Cost Ratio	Alternative 3 – Highest-priority Problems
Total Capital Cost ($ Millions)	$8.30	$5.76	$18.97
Total Benefit Score	404	433	445
Overall Benefit/Cost	48.7	75.1	23.5
Total Flood Reduction (MG)	3.620	2.780	4.743
Cost of Flood Reduction ($/Gallon)	$2.29	$2.07	$4.00

Note:
Results presented in this table are based on watershed-wide alternative models that include the selected projects documented in sections 5.4.1-5.4.3.

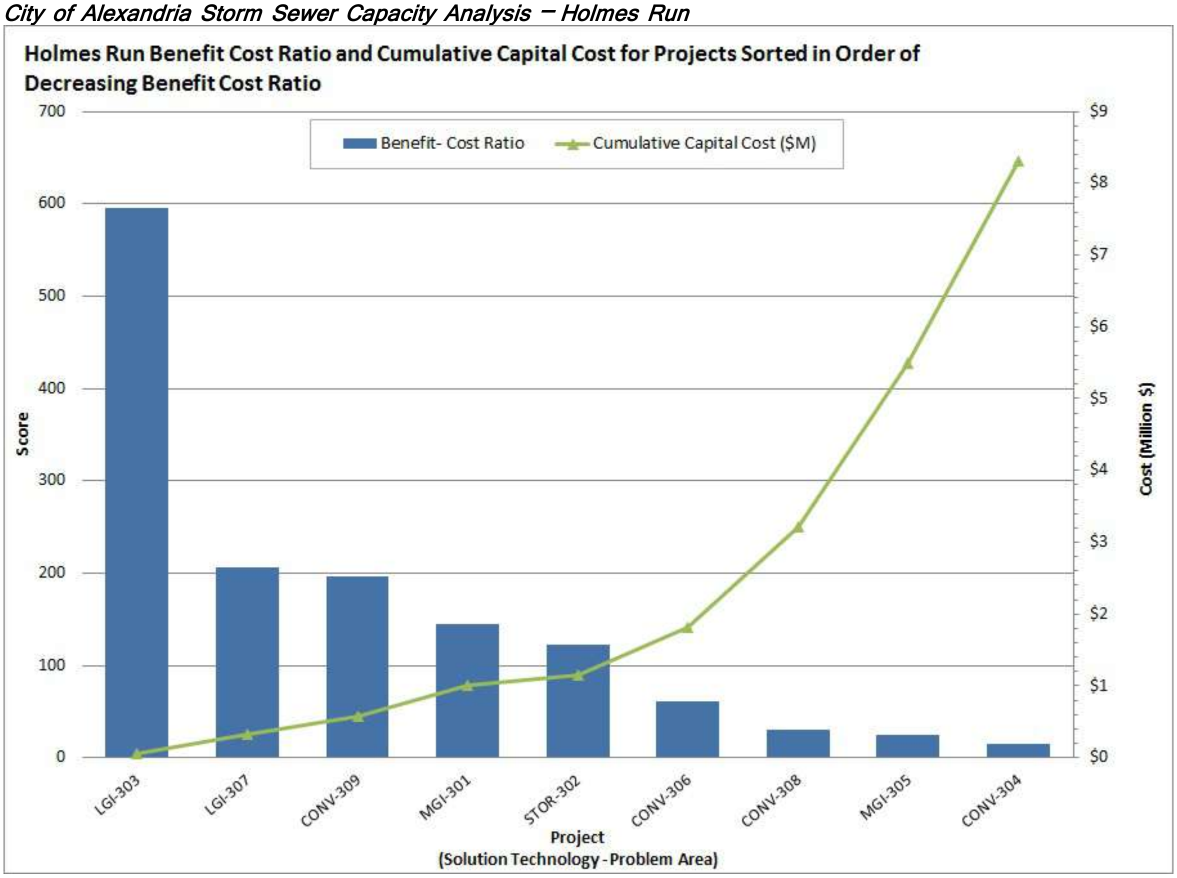
When developing a capital improvement plan, the benefit cost or cost efficiency ($/gallon of flood reduction) are typically used to guide the order in which projects are implemented. Prioritization results for the three watershed-wide alternatives are presented in Figures 5-8 through 5-10.

The top chart shows the benefit cost ratio and the cumulative capital cost of the alternative. The solutions are provided in order of decreasing benefit cost ratio; solutions with the greatest benefit cost ratio are presented on the left and solutions with the lowest benefit cost ratio are presented on the right.

The bottom chart shows the benefit/cost ratio for each solution in the watershed-wide alternative in order of increasing cost/gallon of flood reduction.

Both charts show the cumulative capital cost plotted on the secondary axis. The solutions on both charts are named by the technology: conveyance (CONV), storage (STOR), low green infrastructure (LGI), medium GI (MGI), or high GI (HGI), and the problem area number.

FIGURE 5-8
Alternative 1: Best Cost Efficiency Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



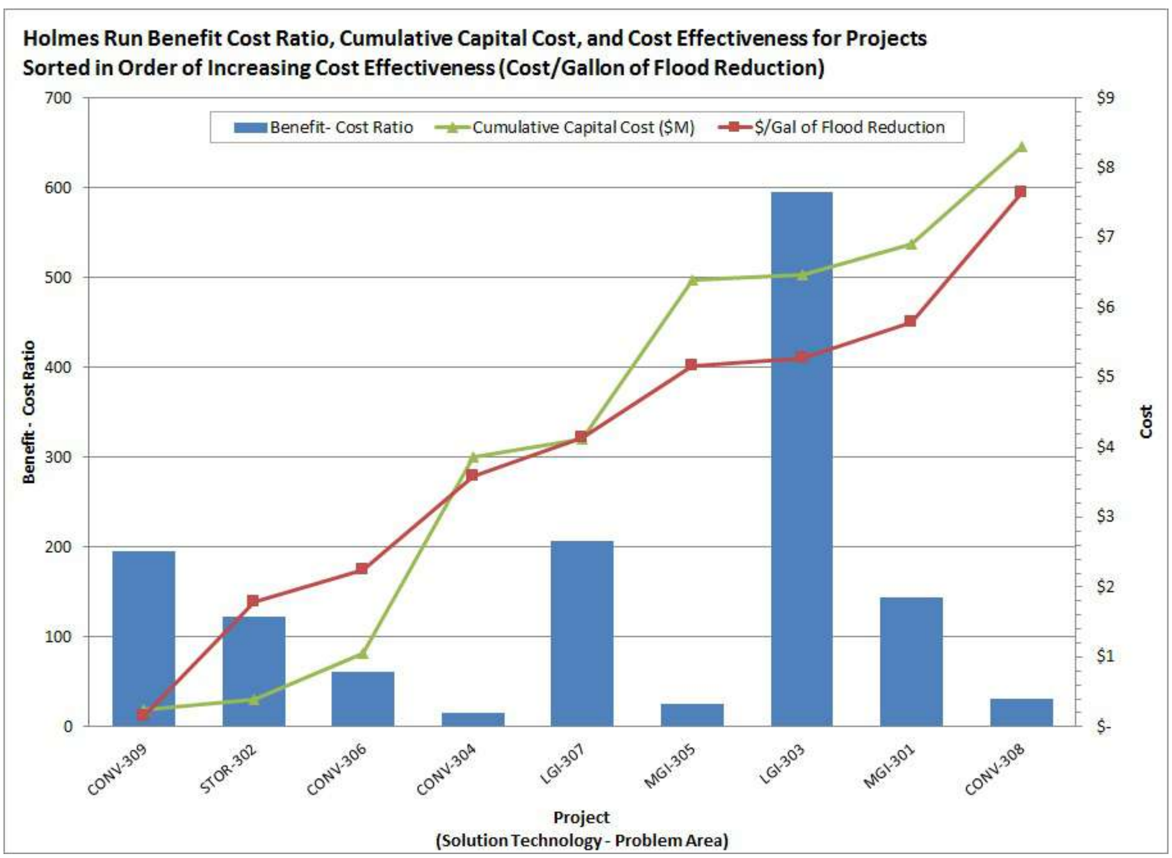
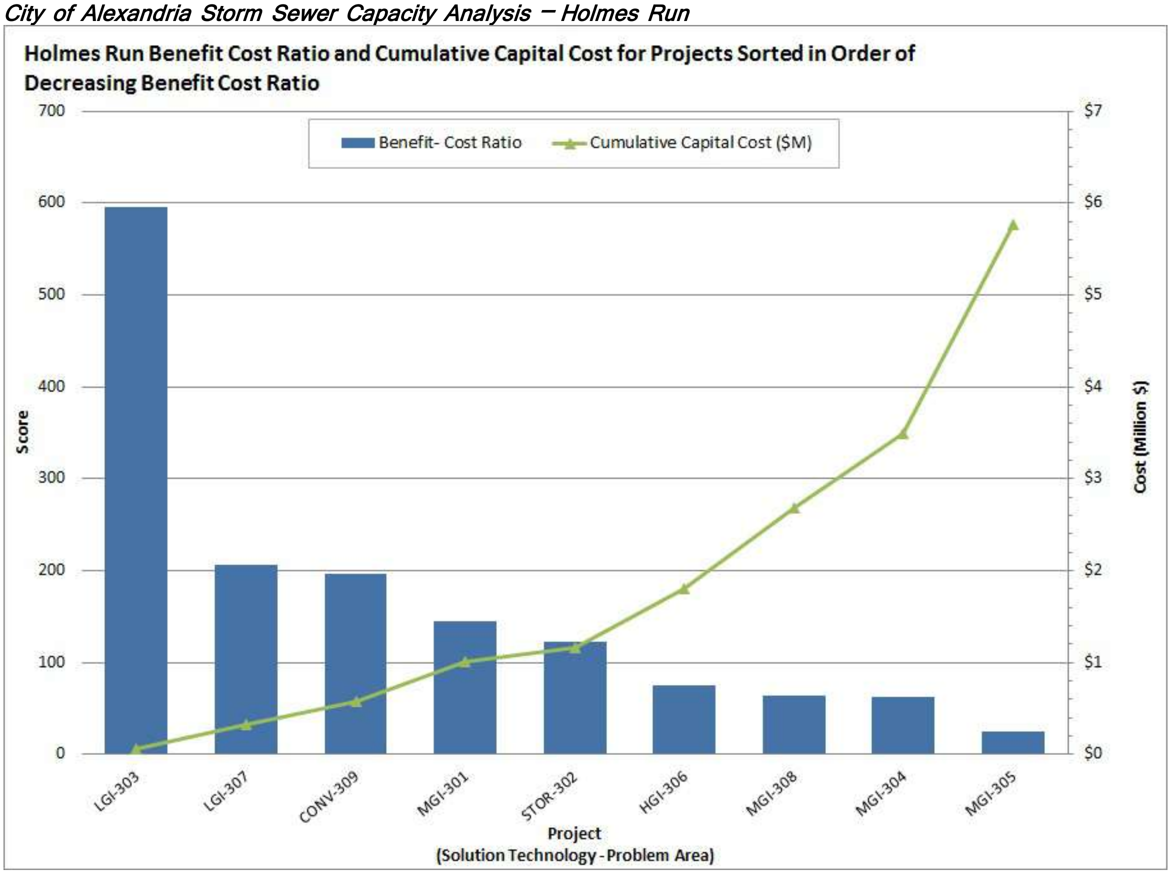


FIGURE 5-9
Alternative 2: Best Benefit/Cost Ratio Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



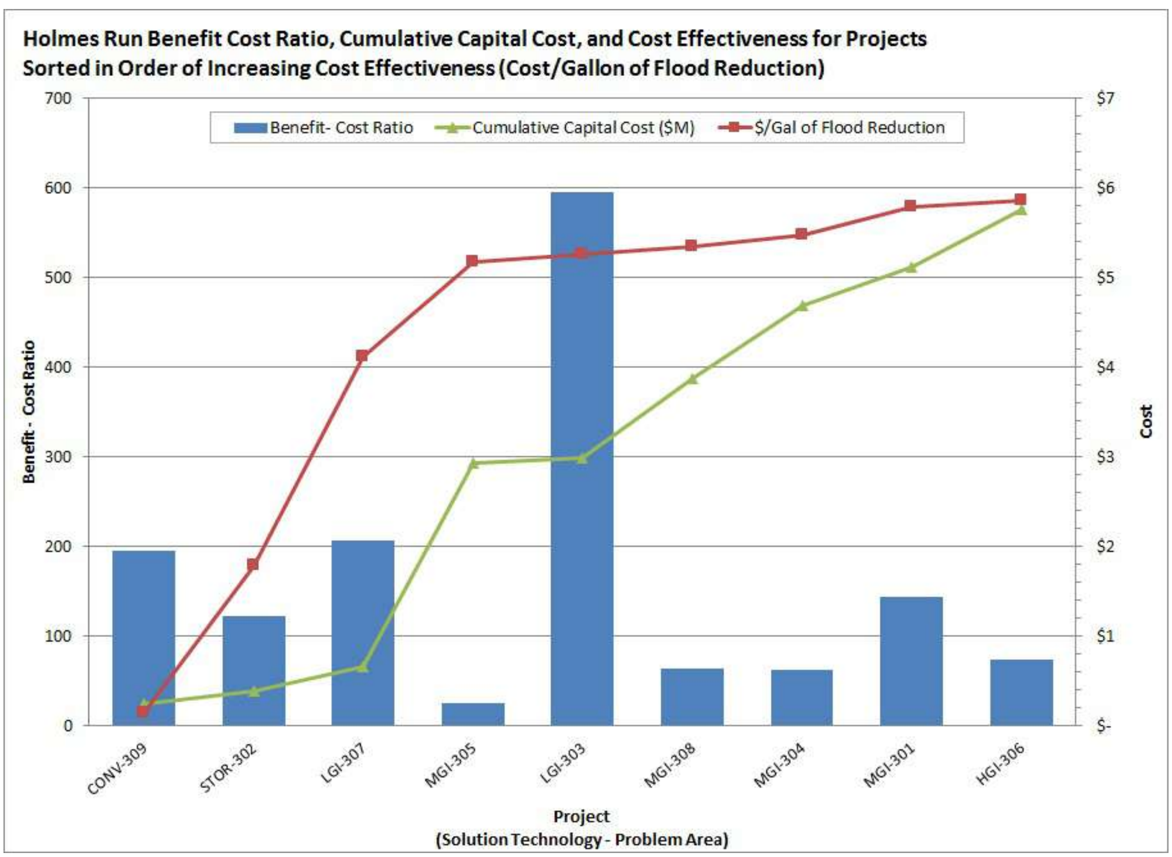
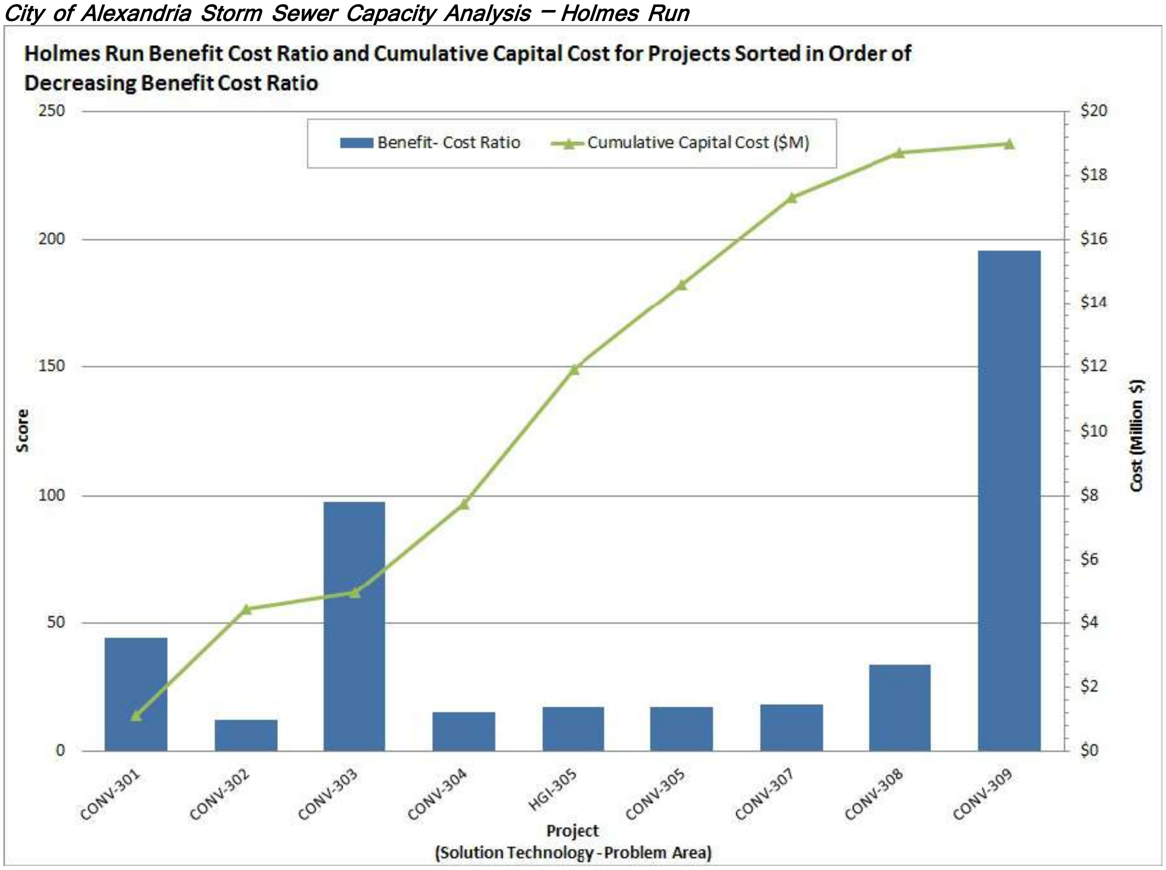


FIGURE 5-10
Alternative 3: Highest Priority Problems Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run



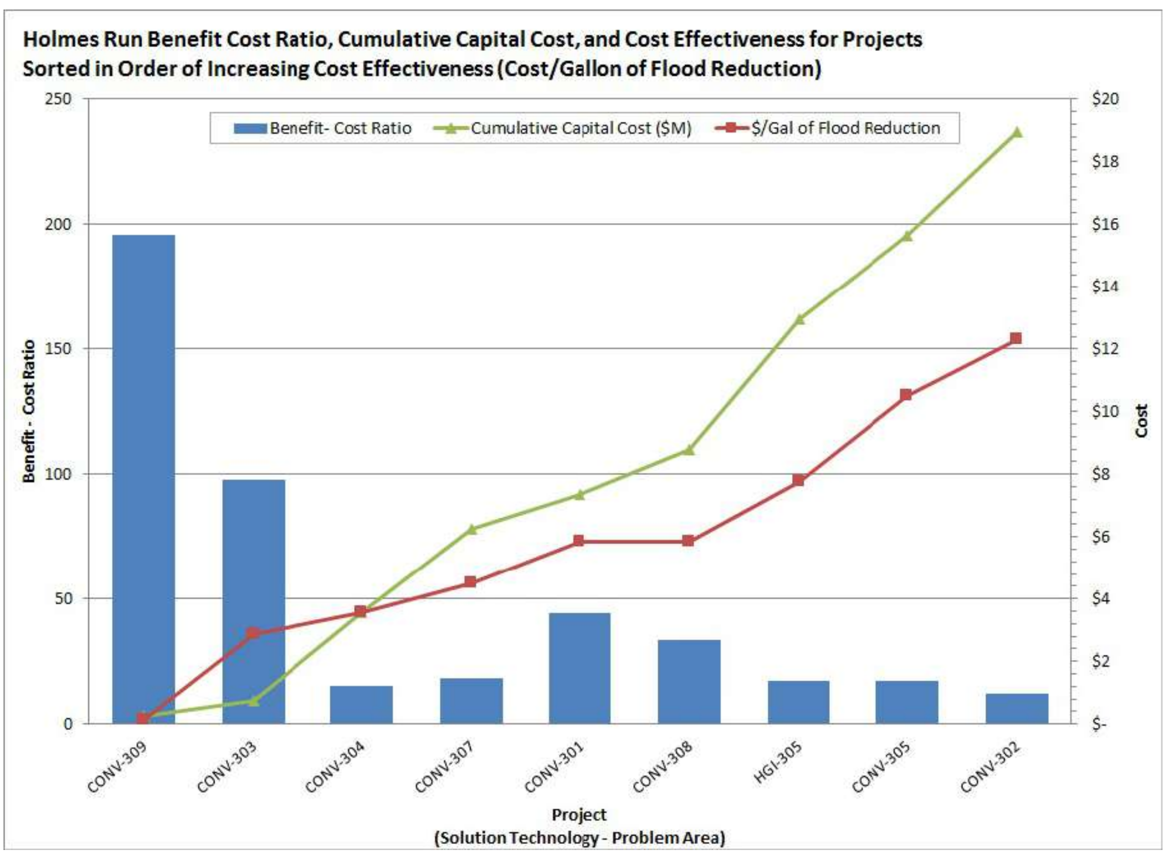


TABLE 5-6
Summary of Watershed-wide Alternative Model Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run

	Alternative 1 Best Cost Efficiency				**Alternative 2 Best Benefit/Cost Ratio**				**Alternative 3 Highest-priority Problems**			
	Conduit Length (LF)	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**	**Conduit Length (LF)**	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**	**Conduit Length (LF)**	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**
Sufficient Capacity	55,400	57%	-	-	50,331	51%	-	-	71,743	73%	-	-
Surcharged[a]	17,666	18%	186	-	18,477	19%	211	-	10,734	11%	145	-
Insufficient Freeboard	12,547	13%	-	-	13,657	14%	-	-	8,926	9%	-	-
Flooded	12,407	13%	45	393,752	15,317	16%	56	484,918	6,616	7%	30	331,889

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

SECTION 6
Summary

The objectives of this phase of the study were to 1) identify and prioritize capacity problems based on modeling results from Task 2 of this project, and 2) develop and prioritize solutions to address those problems. The first objective was accomplished in two steps. The first step included evaluating each stormwater junction in the drainage network using a scoring system to identify problems based on several criteria, including the severity of flooding, proximity to critical infrastructure and roadways, identification of problems by city staff and the public, and opportunity for overland relief. In the next step of this objective, high-scoring junctions (that is, higher-priority problems) were grouped together to form high-priority problem areas. In total, 9 high-priority problem areas were identified in the Holmes Run watershed.

The second objective involved developing and prioritizing solutions to address capacity limitations within the 9 high-priority problem areas. To accomplish this objective, several strategies involving different technologies were examined, including improving conveyance by increasing hydraulic capacity, reducing capacity limitations by adding distributed storage to the system, and reducing stormwater inflows by implementing GI. Each of these strategies required a different modeling approach. Conveyance improvements were modeled by increasing pipe diameter in key locations within the problem area, storage was added as storage nodes based on a preliminary siting exercise, and GI was modeled as a reduction in impervious area at three different implementation levels: high, medium, and low. A single model run was set up and run for each strategy addressing all 9 high-priority problem areas and the results were compiled for the alternatives and prioritization evaluation. Solutions were evaluated based on several criteria, including drainage improvement/flood reduction, environmental compliance, sustainability and social benefits, asset management and maintenance implications, constructability, and public acceptance. Planning-level capital costs were developed for each solution to facilitate a benefit cost analysis and prioritization process.

The results of the solution identification and prioritization analysis show the following:

- In terms of solution technology performance:
  - GI generally has the greatest overall benefit as defined by the solution evaluation scoring system described in this report
  - Conveyance solutions and high implementation of GI generally provide the greatest flood reduction of the technologies/approaches analyzed in Holmes Run
  - Combination of conveyance or storage projects combined with GI generally provides the greatest benefit and flood reduction
- In terms of costs:
  - Low level of GI implementation generally has the greatest benefit /cost score but did not usually meet minimum threshold for flood reduction
  - Conveyance projects generally provide the most economical stormwater volume reduction in terms of dollars per gallon of flood reduction within a high-priority problem area
  - Combination of conveyance and GI generally provides the greatest overall benefit/cost score

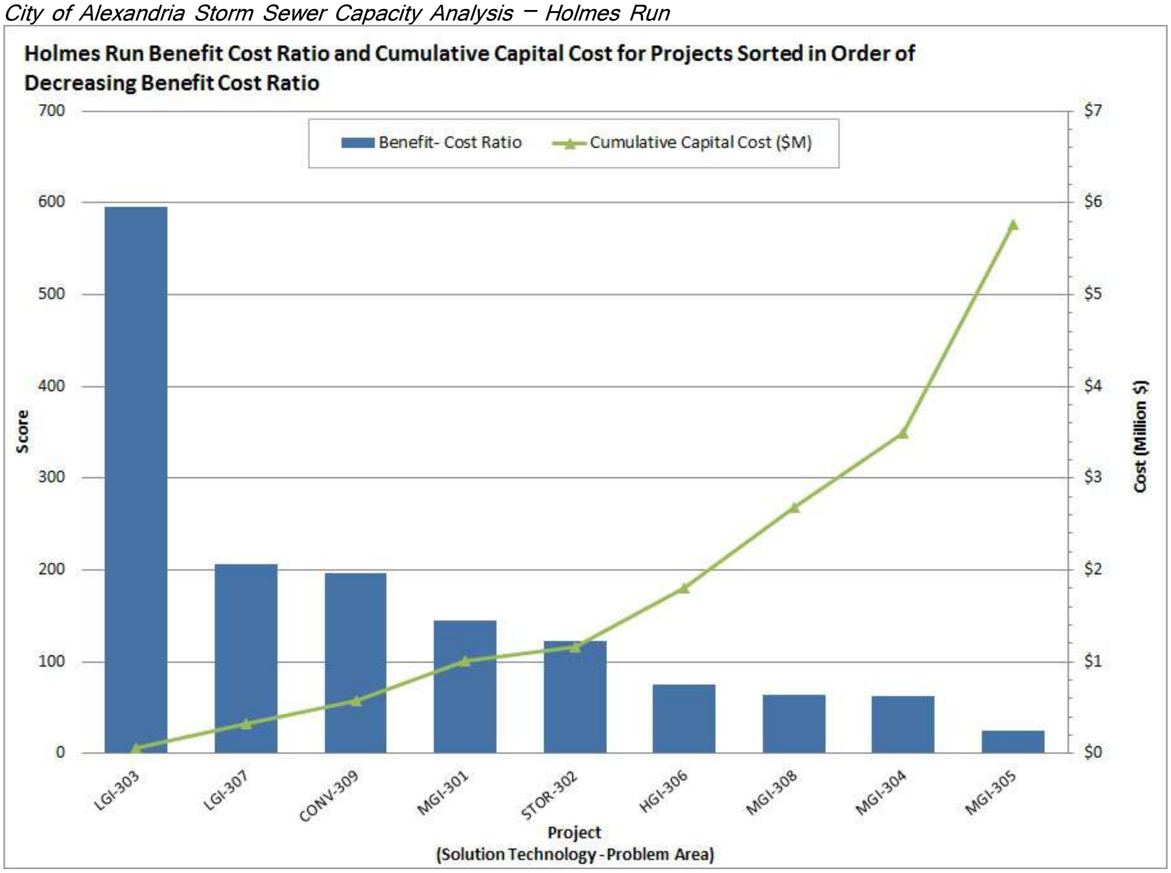
Three watershed-wide alternatives were developed, including:

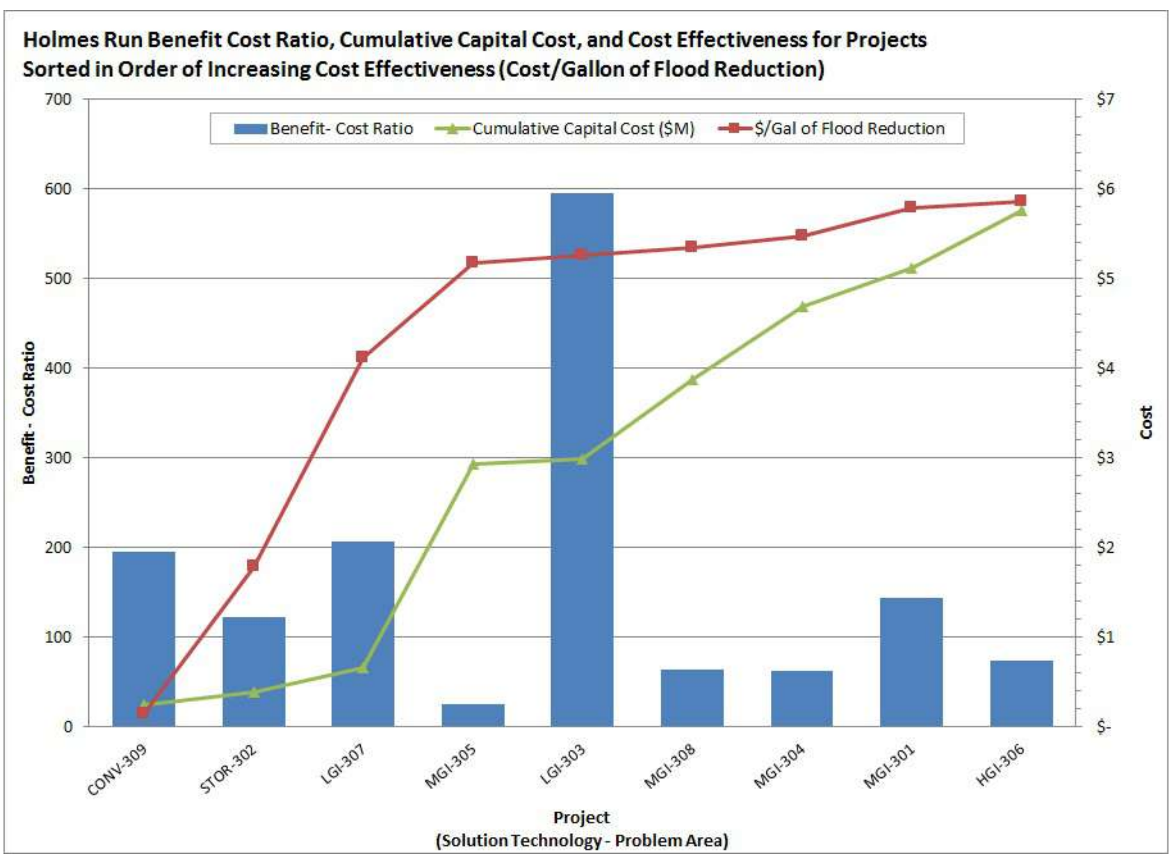
- Alternative 1: Combination of projects with the lowest cost per gallon of flood reduction.
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to address the worst problem areas to the extent practicable

Alternative 1 was built on the objective of providing the best cost efficiency in each of the nine high-priority problem areas. This resulted in a higher total capital cost than Alternative 2, but reduced the flooding in the nine high-priority problem areas by about one million gallons over Alternative 2. Alternative 2 focused on the solutions that had the highest benefit/cost ratio in each of the nine high-priority problem areas. This focus resulted in the highest benefit/cost ratio and the lowest cost per million gallons of flood reduction of the three alternatives. Conversely, Alternative 2 resulted in the smallest flood volume reduction of the three alternatives. Alternative 3, which focused on providing the greatest overall relief within the nine high-priority problem areas, resulted in the highest overall benefit score and the greatest total flood reduction but at the highest cost. Therefore, Alternative 2 is the recommended alternative as it is the most cost-effective option, both from flood reduction and benefit/cost perspective. Two suggested prioritizations of watershed-wide Alternative 2 projects are provided in Figure 6-1; projects can be prioritized either based on overall benefit/cost ratio or cost efficiency (cost per gallon of flood reduction).

It should be noted that the model does not include analysis on private property, but applies assumed runoff loads as inputs to the public conveyance system. The City chose not to include existing private or most public stormwater management facilities (e.g., detention and retention ponds) upstream of the modeled collection system, because of the limited available information on these facilities, and a concern that the facilities may not be performing as designed. When the City moves forward into detailed evaluation and design of selected projects it will be important to more fully evaluate any existing stormwater management facilities.

FIGURE 6-1
Alternative 2: Best Benefit/Cost Ratio Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Holmes Run





SECTION 7
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Appendix A
Conveyance Solutions

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Holmes Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
301	001234STMP	001931IN	001940IN	296.983	Circular	1.5	0	2.5		1.923	1	0.013
301	002870STMP	001940IN	002008IN	284.217	Circular	1.5	0	2.5		3.67	1	0.013
301	002533STMP	002008IN	002010IN	296.859	Circular	1.75	0	2		6.181	1	0.013
301	002535STMP	002010IN	000670SMH	314.973	Circular	1.75	0	2.5		6.753	1	0.013
301	004622STMP	002601IN	002602IN	36.312	Circular	1.75	0	2.5		4.373	1	0.013
301	004619STMP	002602IN	002649IN	224.866	Circular	1.75	0	2.5		5.496	1	0.013
301	004620STMP	002279IN	000765SMH	48.613	Circular	2	0	3		7.2	1	0.013
301	004621STMP	002572IN	000926SMH	63.523	Circular	2	0	3		1.475	1	0.013
301	004617STMP	002575IN	000927SMH	353.021	Circular	2.25	0	3.5		4.05	1	0.013
301	004612STMP	002578IN	002575IN	22.43	Circular	3	0	4.5		2.978	1	0.013
301	001231STMP	003167IN	003168IN	290.032	Circular	1.5	0	2		0.524	1	0.013
301	002007STMP	003168IN	003169IN	77.327	Circular	1.75	0	2.5		0.272	1	0.013
302	005173STMP	003169IN	001049SMH	174.809	Circular	2.25	0	3.5		2.984	1	0.013
302	005174STMP	003171IN	003183IN	293.635	Circular	2.5	0	4.5		2.408	1	0.013
302	005175STMP	003172IN	003171IN	35.32	Circular	2.5	0	3		2.746	1	0.013
302	005177STMP	002627IN	000941SMH	86.29	Circular	4	0	5.5		2.3	1	0.013
302	005178STMP	002628IN	000943SMH	42.193	Circular	3.5	0	5		5.316	1	0.013
302	005138STMP	002649IN	002572IN	93.571	Circular	4	0	5		3.695	1	0.013
302	005139STMP	002653IN	002601IN	176.374	Circular	3.5	0	5		3.612	1	0.013
302	005152STMP	002654IN	002653IN	80.491	Circular	1.75	0	2.5		7.574	1	0.013
302	005155STMP	002662IN	002665IN	26.835	Circular	2	0	3		8.109	1	0.013
302	005189STMP	002665IN	002654IN	52.092	Circular	4	0	5		3.776	1	0.013
302	005191STMP	002677IN	002578IN	159.526	Circular	4.5	0	6		7.868	1	0.013
302	004938STMP	002957IN	002960IN	65.615	Circular	3	0	4		7.574	1	0.013
302	005207STMP	002960IN	002961IN	201.197	Circular	4.5	0	6.5		5.88	1	0.013
302	005209STMP	002961IN	002962IN	338.331	Circular	5	0	5.5	8	3.904	1	0.013
302	005851STMP	002962IN	002963IN	167.4	Circular	5	0	5.5	8	3.447	1	0.013
302	005216STMP	002963IN	000199IO	211.93	Circular	5	0	5.5	8	0.727	1	0.013
302	005206STMP	003020IN	000997SMH	242.205	Circular	1.75	0	2.5		3.765	1	0.021
302	005859STMP	003022IN	003020IN	136.682	Circular	5	0	6.5		3.841	1	0.013
302	004932STMP	003135IN	003136IN	267.952	Circular	4.5	0	5.5		2.926	1	0.013
302	004933STMP	003136IN	003172IN	144.332	Circular	4.5	0	6		2.926	1	0.013
302	005204STMP	003149IN	003167IN	66.441	Circular	2.5	0	3.5		0.737	1	0.013
302	004939STMP	003152IN	003167IN	85.668	Circular	2.5	0	3.5		0.315	1	0.013
302	005205STMP	004280IN	004281IN	245.878	Circular	2.5	0	3		1.059	1	0.013
302	005208STMP	004281IN	001327SMH	268.411	Circular	3	0	4.5		6.052	1	0.013
302	005860STMP	003183IN	003185IN	335.344	Circular	5.5	0	7		3.137	1	0.013
303	005203STMP	003185IN	001045SMH	236.957	Circular	2.5	0	4		1.304	1	0.013
303	005200STMP	003189IN	003185IN	128.803	Circular	2	0	3.5		1.305	1	0.013
303	005864STMP	003202IN	001050SMH	123.25	Circular	2.39	0	5		0.982	1	0.013
303	005865STMP	003206IN	003207IN	180.401	Circular	2.39	0	4	7	1.935	1	0.013
303	005866STMP	003207IN	003215IN	258.243	Circular	2.39	0	4.5		0.86	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Holmes Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
303	005867STMP	003214IN	003901IN	264.227	Circular	2.39	0	3	6	0.886	1	0.013
303	005873STMP	003215IN	003214IN	159.591	Circular	2.39	0	2.5	4	0.79	2	0.013
304	003761STMP	003220IN	003221IN	9.586	Circular	1.5	0	2		1.256	1	0.013
304	002857STMP	003221IN	001047SMH	127.333	Circular	1.5	0	2.5		0.457	1	0.013
304	002637STMP	003331IN	001082SMH	108.137	Circular	1.5	0	3		5.131	1	0.013
304	002641STMP	003364IN	001096SMH	138.38	Circular	1.75	0	2		1.178	1	0.013
304	002642STMP	003367IN	003364IN	228.4	Circular	1.5	0	2.5		2.513	1	0.013
304	003735STMP	003368IN	003367IN	152.536	Circular	1.5	0	2.5		2.268	1	0.013
304	003737STMP	003373IN	000400ND	217.764	Circular	1.5	0	2		0.591	1	0.013
304	002638STMP	003813IN	000268IO	214.86	Circular	1.5	0	2.5		1.81	1	0.013
304	003762STMP	003840IN	001273SMH	21.425	Circular	1.5	0	2		-1.116	1	0.013
304	002937STMP	003846IN	009064IN	61.258	Circular	1.25	0	2		1.404	1	0.013
304	002947STMP	003901IN	001218SMH	80.317	Circular	1.25	0	1.5		1.731	1	0.013
304	002938STMP	004241IN	004242IN	272.777	Circular	1.25	0	2		2.109	1	0.013
304	002645STMP	004242IN	001327SMH	113.266	Circular	1.25	0	2		2.877	1	0.013
304	005875STMP	004245IN	001328SMH	11.862	Circular	4.5	0	5.5		4.063	1	0.013
304	014620STMP	004254IN	001344SMH	253.022	Circular	4.5	0	4	7	3.985	1	0.013
304	003818STMP	004255IN	004254IN	61.446	Circular	4	0	6		1.022	1	0.013
304	005933STMP	009064IN	003813IN	143.522	Circular	4.5	0	6		1.205	1	0.013
304	003819STMP	000281ND	000764SMH	308.15	Circular	4	0	5.5		2.576	1	0.013
304	003822STMP	000286ND	000773SMH	35.482	Circular	1.5	0	2		0.798	1	0.013
304	002625STMP	000400ND	001097SMH	103.981	Circular	1.75	0	2.5		0.591	1	0.021
304	003828STMP	000402ND	000576IO	53.896	Circular	1.5	0	3.5		10.01	1	0.013
304	002574STMP	000528ND	001273SMH	313.293	Circular	1.5	0	2.5		1.953	1	0.013
304	003700STMP	000670SMH	002956IN	88.71	Circular	2.5	0	3.5		8.455	1	0.013
304	004302STMP	000752SMH	000753SMH	45.169	Circular	3	0	4		0.908	1	0.013
304	002626STMP	000753SMH	001248SMH	135.141	Circular	2	0	3		0.932	1	0.013
304	002630STMP	000754SMH	000752SMH	182.675	Circular	1.75	0	3		1.248	1	0.013
304	002632STMP	000755SMH	000752SMH	178.193	Circular	1.5	0	2.5		2.643	1	0.013
304	001106STMP	000756SMH	000922SMH	248.49	Circular	1.75	0	2.5		4.828	1	0.013
304	004294STMP	000761SMH	000756SMH	46.85	Circular	2.5	0	3.5		0.44	1	0.013
304	004295STMP	000763SMH	000769SMH	345.517	Circular	3	0	3.5		2.94	1	0.013
304	004299STMP	000764SMH	000763SMH	327.04	Circular	3.5	0	4.5		2.556	1	0.013
304	004300STMP	000765SMH	000281ND	41.214	Circular	3.5	0	4		2.576	1	0.013
304	003765STMP	000766SMH	000765SMH	359.573	Circular	3.5	0	4.5		2.928	1	0.013
304	003766STMP	000767SMH	000766SMH	256.771	Circular	3.5	0	5		4.432	1	0.013
304	003771STMP	000769SMH	000286ND	137.814	Circular	2	0	3		0.798	1	0.021
304	003782STMP	000773SMH	000774SMH	115.488	Circular	1.75	0	3		1.23	1	0.021
304	003729STMP	000774SMH	000775SMH	16.134	Circular	1.5	0	2.5		-3.471	1	0.013
304	002921STMP	000873SMH	000761SMH	199.994	Circular	1.5	0	2.5		1.317	1	0.013
304	003731STMP	000874SMH	000873SMH	125.712	Circular	1.5	0	2.5		6.796	1	0.013
304	003736STMP	000922SMH	000923SMH	80.487	Circular	1.5	0	2		2.535	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Holmes Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
304	005934STMP	000923SMH	000931SMH	185.042	Circular	4.5	0	6		1.87	1	0.013
305	003873STMP	000924SMH	000922SMH	114.191	Circular	2	0	3		2.899	1	0.013
305	003877B	000925SMH	000924SMH	279.468	Circular	4.5	0	6.5		2.876	1	0.013
305	003882B	000926SMH	000925SMH	291.254	Circular	5	0	8.5		4.339	1	0.013
305	003869STMP	000927SMH	000928SMH	317.678	Circular	5	0	6.5		3.599	1	0.013
305	003870STMP	000928SMH	000929SMH	111.481	Circular	4.5	0	6.5		0.547	1	0.013
305	003877A	000929SMH	000931SMH	124.986	Circular	4.5	0	6.5		0.752	1	0.013
305	003874STMP	000930SMH	000934SMH	263.215	Circular	4	0	5.5		2.162	1	0.013
305	003878STMP	000931SMH	000930SMH	77.245	Circular	4	0	5		2.835	1	0.013
305	003882A	000933SMH	000754SMH	102.231	Circular	5	0	8.5		3.6	1	0.013
305	003887STMP	000934SMH	000933SMH	62.802	Circular	5	0	7.5		2.229	1	0.013
306	004659STMP	000938SMH	000937SMH	176.196	Circular	1.5	0	2.5		3.422	1	0.013
306	004662STMP	000939SMH	000938SMH	302.471	Circular	1.5	0	2.5		3.422	1	0.013
306	006063STMP	000940SMH	000939SMH	312.489	Circular	1.25	0	2		4.376	1	0.013
306	006064STMP	000941SMH	000940SMH	86.847	Circular	1.25	0	2		4.673	1	0.013
306	005923STMP	000943SMH	002627IN	149.354	Circular	2.5	0	3		7.309	1	0.013
306	005925STMP	000951SMH	001043SMH	206.592	Circular	2.5	0	3		1.075	1	0.013
306	004972STMP	000995SMH	003368IN	327.455	Circular	1.5	0	3		3.823	1	0.013
306	006115STMP	000996SMH	000995SMH	25.895	Circular	1.5	0	3		3.707	1	0.013
307	004074STMP	000997SMH	003019IN	56.504	Circular	2.5	0	4		4.088	1	0.013
307	003710STMP	000999SMH	003022IN	154.648	Circular	2.5	0	4		4.785	1	0.013
307	003794STMP	001043SMH	001044SMH	229.391	Circular	2.5	0	4		5.458	1	0.013
307	004705STMP	001044SMH	001219SMH	49.325	Circular	3	0	5.5		1.034	1	0.013
307	004706STMP	001045SMH	001046SMH	72.92	Circular	3	0	5		2.51	1	0.013
307	004710STMP	001046SMH	003206IN	93.394	Circular	3	0	5		1.21	1	0.013
307	004020A	001047SMH	001048SMH	263.667	Circular	3.5	0	6.5		1.656	1	0.013
307	004020B	001048SMH	003202IN	157.913	Circular	3.5	0	6.5		1.656	1	0.013
307	004711STMP	001050SMH	003206IN	36.42	Circular	3	0	4.5		0.632	1	0.013
307	003799STMP	001081SMH	001083SMH	43.046	Circular	3	0	4		3.048	1	0.013
307	003709STMP	001082SMH	001081SMH	108.168	Circular	2.5	0	4		4.939	1	0.013
307	003711STMP	001083SMH	001084SMH	127.147	Circular	2.25	0	3.5		5.549	1	0.013
307	004019STMP	001084SMH	001085SMH	60.598	Circular	3.5	0	6.5		5.941	1	0.013
307	014584STMP	001096SMH	003373IN	417.573	Circular	3.5	0	6.5		0.551	1	0.013
308	005928STMP	001097SMH	000402ND	27.862	Circular	1.5	0	2		0.591	1	0.013
308	006124STMP	001219SMH	001220SMH	74.548	Circular	2	0	3		0.309	1	0.013
308	004884STMP	001220SMH	001221SMH	23.243	Circular	1.5	0	2		1.291	1	0.013
308	004885STMP	001221SMH	001222SMH	98.122	Circular	1.5	0	3		0.622	1	0.013
308	004664STMP	001222SMH	000266IO	181.77	Circular	3	0	4.5		1.81	1	0.013
308	014622STMP	001241SMH	003919IN	268.336	Circular	3	0	3.5		2.743	1	0.013
308	014590STMP	001242SMH	001241SMH	65.012	Circular	3	0	4.5		2.219	1	0.013
308	014631STMP	001243SMH	001242SMH	127.741	Circular	3	0	4		2.219	1	0.013
308	014591STMP	001248SMH	003846IN	110.423	Circular	3	0	4.5		0.969	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Holmes Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
308	014604STMP	001273SMH	001245SMH	239.963	Circular	2	0	2.5		4.93	1	0.013
308	006125STMP	001327SMH	001243SMH	111.831	Circular	2	0	2.5		2.219	1	0.013
308	004761STMP	001328SMH	001341SMH	195.455	Circular	1.5	0	2.5		0.957	1	0.013
309	003561STMP	001341SMH	001340SMH	44.101	Circular	1.25	0	3.5		1.088	1	0.013
309	003559STMP	001342SMH	001328SMH	90.256	Circular	1.5	0	4		2.818	1	0.013
309	003560STMP	001344SMH	004251IN	288.356	Circular	1.25	0	3.5		2.747	1	0.013
309	003566STMP	001346SMH	004255IN	143.742	Circular	1.25	0	3.5		0.459	1	0.013
309	003567STMP	000280IO	001346SMH	139.246	Circular	3	0	3.5		2.91	1	0.013

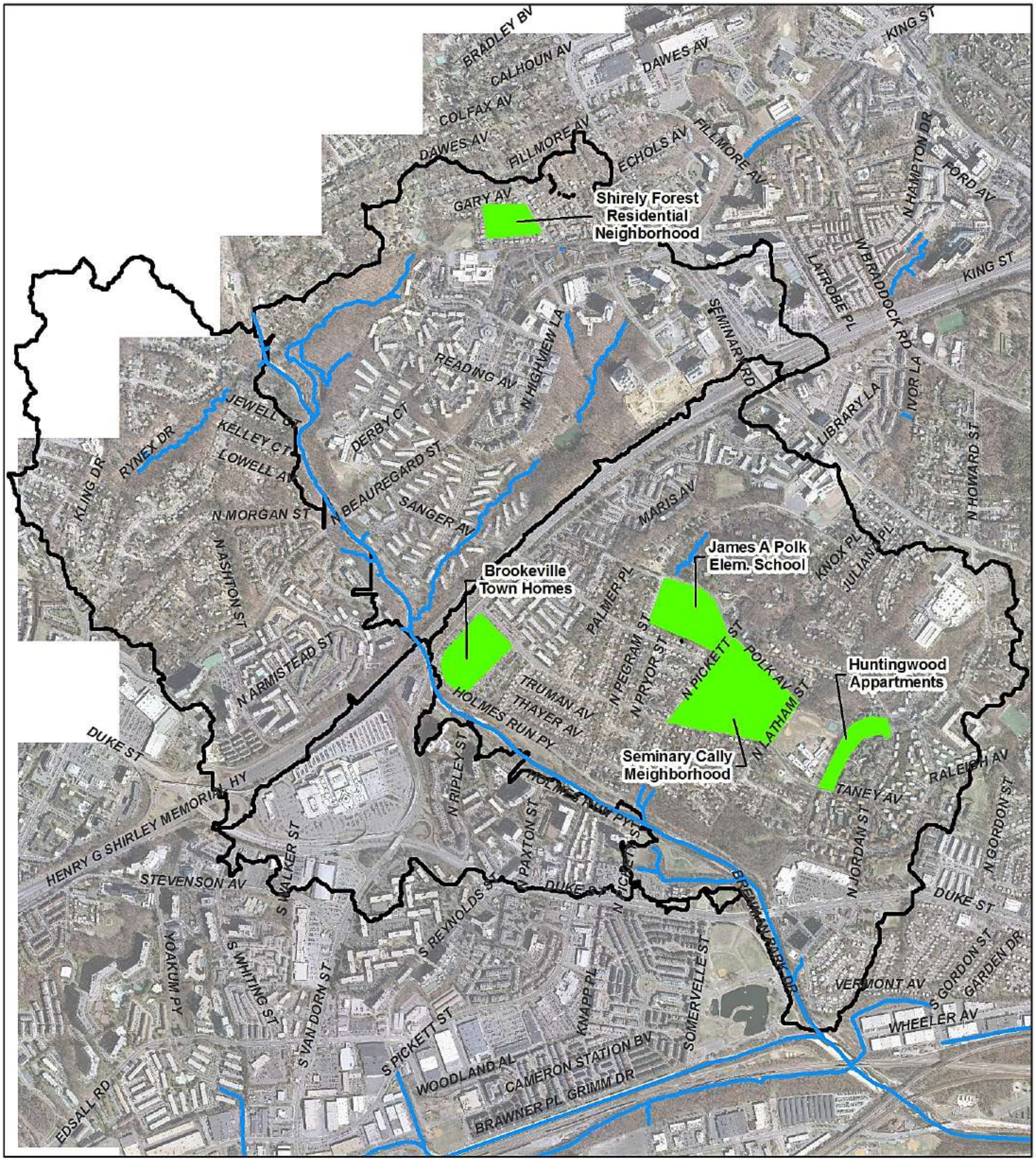
Appendix B
Storage Solutions

Appendix B - Storage Solutions

Summary of Storage Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	Storage ID	Overflow Node	Discharge Node	Storage Area (ac)	Storage Area (ft^2)	Overflow Weir Crest	Overflow Weir Crown	Storage Invert Elevation (ft)	Storage Rim Elevation (ft)	Storage Depth (ft)	Notes
302	Node5359	000843ND	000849ND	0.03	1,351	123.8	120.8	108.9	117	8.5	

Appendix C
Green Infrastructure Concept Plans



LEGEND
- City of Alexandria Streams
- Concept Plan Locations
- Subwatersheds

Task 4 Green Infrastructure Program Concepts for Holmes Run

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

0 750 1,500 Feet

N

CH2MHILL

Potential Sites for Task 4 Concept Development in Holmes Run

PREPARED FOR: City of Alexandria TE&S Department

COPY TO: File

PREPARED BY: CH2M HILL

DATE: March 8, 2016

PROJECT NUMBER: 240027

The following is documentation of the sites identified as potential locations for green infrastructure (GI) concept development in Holmes Run. For each site a program and the elements of the program are identified with field notes as well as pros and cons of GI implementation. Sites are described with the southernmost site in Holmes Run first, moving north into the watershed. A map of the watershed and all potential sites, as well as a detailed map of each individual site, is provided in Appendix A for reference.

Huntingwood Apartments N. Howard St (400-600 Blocks) 90° Parking

N Howard St (Looking North)

N. Howard St (Looking North)

Program Type: Green Buildings, Green Parking

GI Concepts: Planters/Bioretention, Porous Pavement

Field Notes:

- Bioretention/Planters can be placed between the sidewalks and curbs or between sidewalks and buildings to capture runoff from roof drains
- Planters can be placed at the base of buildings.
- Soils in large grass areas could be amended
- Wide street parking , relatively empty with crown to direct flow to curb

Pros:

- Large stormwater capture potential

- Lateral slope of street towards the parking area makes capture easy
- Parking areas are typically easier and more cost effective to implement
- Significant area between buildings and sidewalk for infilatration.
- Good infiltration potential
- Downstream capacity limitations are severe

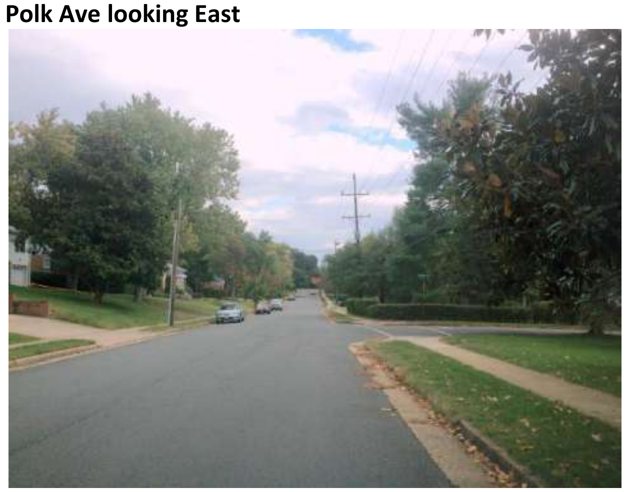
Cons:

- Steep longitudinal slope decreases effectiveness of GI practices
- Near the bottom of the watershed

Seminary Valley Neighborhood

N. Naylor St looking South

Polk Ave looking East



Program Type: Green/Blue Streets - Residential

GI Concepts: Porous Pavement combined with Surface Storage.

Field Notes:

- Wide residential streets with light use of on street parking.
- Shallow crown of roads
- Long stretches of road with shallow longitudinal slopes
- Drains to low point at Taney Avenue and N. Naylor Street

Pros:

- City owned property
- Limited number of inlets
- Targets a known problem area

Cons:

- Limited Inlets and possible inlet capacity at low point near Polk Avenue and N. Naylor Street may cause private property flooding.

Brookville Town Homes

Head on parking in private alleys

Parallel parking in private alleys

Program Type: Green Alleys

GI Concepts: Porous pavement, Bioretention/Planters and Amended Soils

Field Notes:

- Wide alley/driveway's with adjacent parking.
- Cut out in curbs allows excess flow from disconnected roof drains to flow onto alleyways.

Pros:

- Large potential stormwater capture
- Parking areas typically are simpler construction and more cost-effective to implement
- Within a modeled area of flooding
- Existing pavement is deteriorated and in need of repair.
- Parking area and alleyway is highly visible to the townhome residents.

Cons:

- Private property
- Parking area and alleyways are only visible to the townhome residents and has poor visibility by other City residents

James A Polk Elementary School

Polk Elementary School looking South

N. Pickett St and Polk Ave looking West

Program Type: Green Schools, Open Space

GI Concepts: Porous Pavement, Bio Retention/Planters, Cisterns, Green/Blue Roofs, Amended Soils, Detention

Field Notes:

- Existing above grade inlet structure in the North West Corner of the property
- Large open areas surrounding school
- Pavement for driveway, parking area and basket ball court on east side is new
- Large asphalt paved area on north west side of property is old.
- Pavement for Bus loop is new
- Possible vault and/or bio retention on east side of school near play ground adjacent to Polk Avenue
- Possible location for underground storage in open area near corner of Polk Avenue and N. Pegram Street

Pros:

- Large open areas
- Large potential for stormwater capture
- Targets a known problem area
- Green space with depression available for detention
- Highly visible by City Residents
- Educational opportunities at the school
- Open space and parking areas typically easier and more cost-effective to implement

Cons:

- Significant area of pavement for possible conversion to porous pavement is relatively new
- Improvements limited to summer months when school is out
- Construction would be highly visible to local residents
- School is not located near major cross streets requiring construction traffic to travel through residential neighborhoods

Shirley Forest Residential Neighborhood

Forrestal Ave looking East

Forrestal Ave looking West

Program Type: Blue/Green Streets

GI Concepts: Porous Pavement

Field Notes:

- Flat longitudinal and lateral slopes
- Existing pavement in poor condition
- Standard gutter and curb
- Standard residential width streets (32 feet)

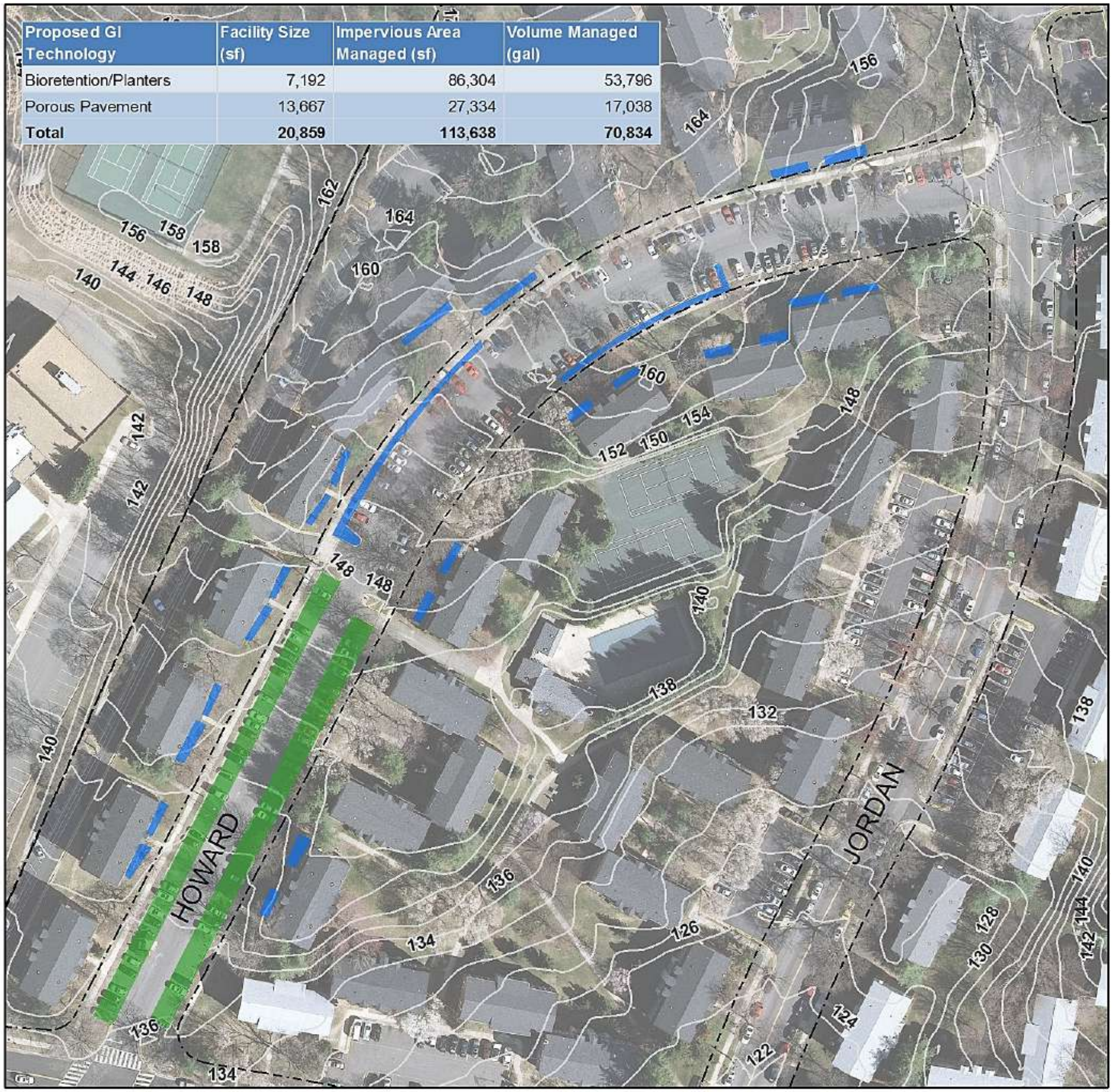
Pros:

- Existing pavement is in poor condition
- Shallow slopes allow for short term storage

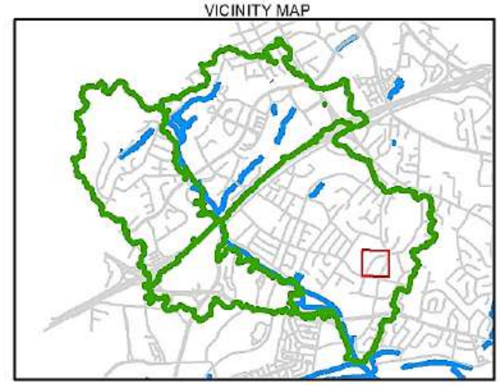
Cons:

- Temporary impact to local residential parking during construction
- Large number of inlets to be retrofitted

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal)
Bioretention/Planters	7,192	86,304	53,796
Porous Pavement	13,667	27,334	17,038
Total	**20,859**	**113,638**	**70,834**



VICINITY MAP



LEGEND

- Contours (ft)
- Parcels
- Watershed
- City of Alexandria Streams

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 50 100 200
Feet

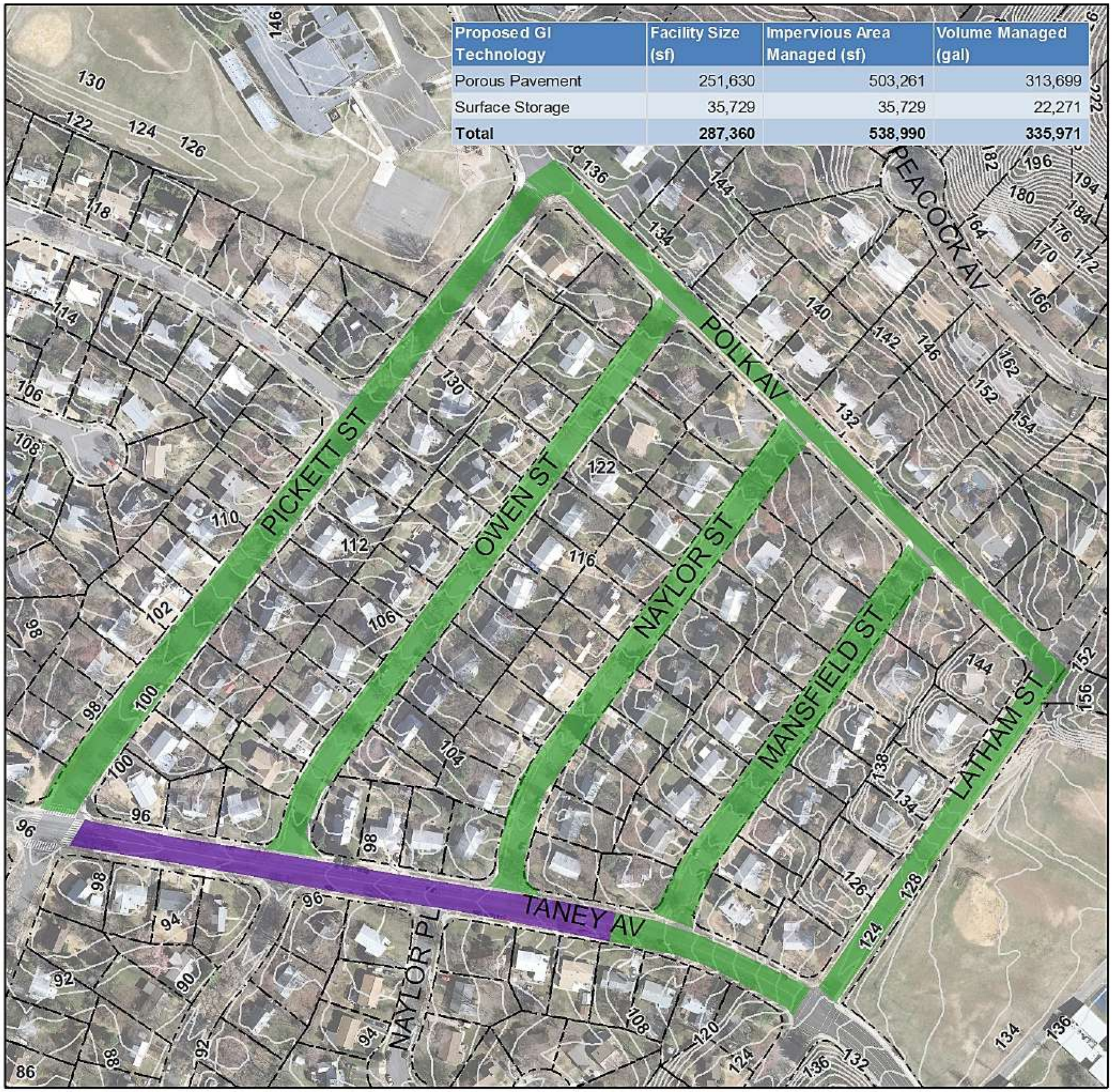
Huntingwood Apts

Green Building, Green Parking

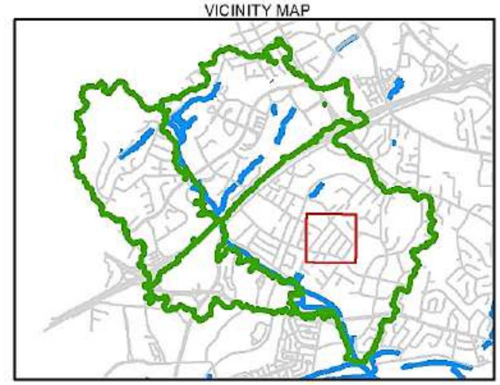
Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal)
Porous Pavement	251,630	503,261	313,699
Surface Storage	35,729	35,729	22,271
Total	**287,360**	**538,990**	**335,971**



VICINITY MAP



LEGEND

- Contours (ft)
- Parcels
- Watershed
- City of Alexandria Streams

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 90 180 360
Feet

Seminary Valley Neighborhood

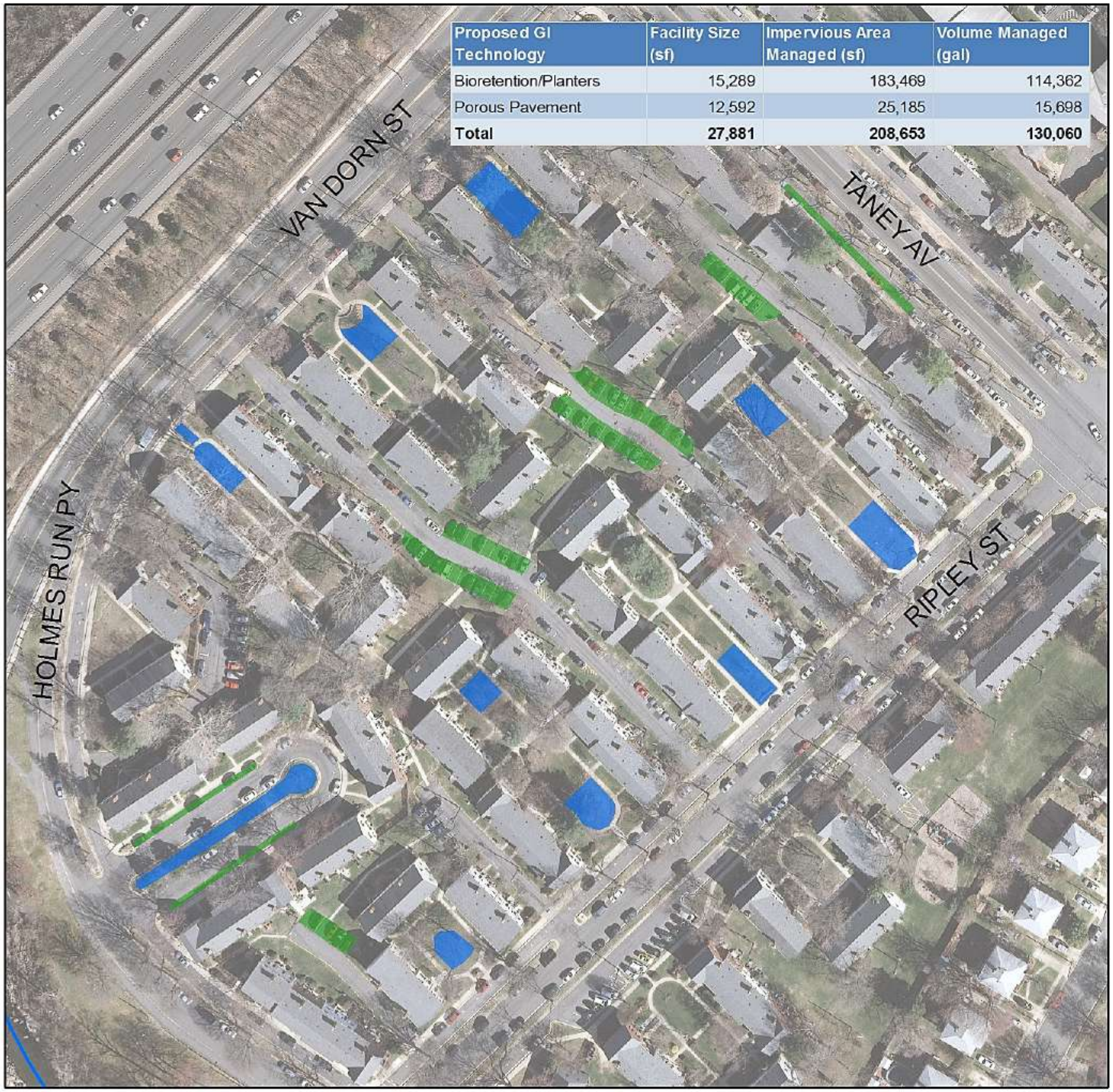
Green/Blue Street

Task 4 - Identify Problems and Develop Solutions

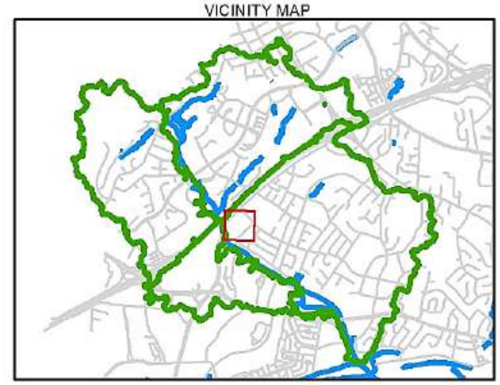
City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal)
Bioretention/Planters	15,289	183,469	114,362
Porous Pavement	12,592	25,185	15,698
Total	**27,881**	**208,653**	**130,060**



VICINITY MAP



LEGEND

- Contours (ft)
- Parcels
- Watershed
- City of Alexandria Streams

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 55 110 220
Feet

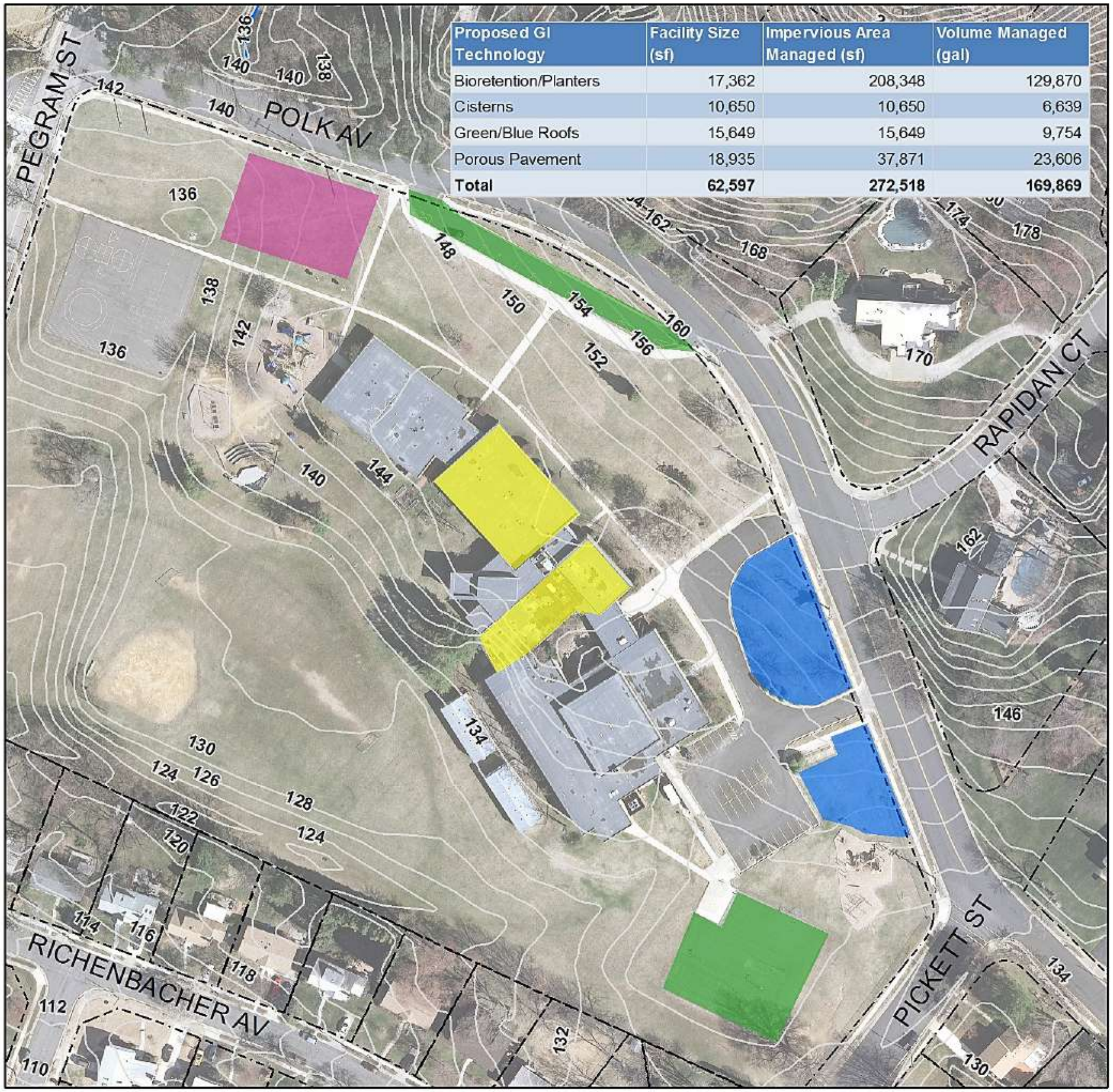
Brookeville Town Homes

Green Alleys

Task 4 - Identify Problems and Develop Solutions

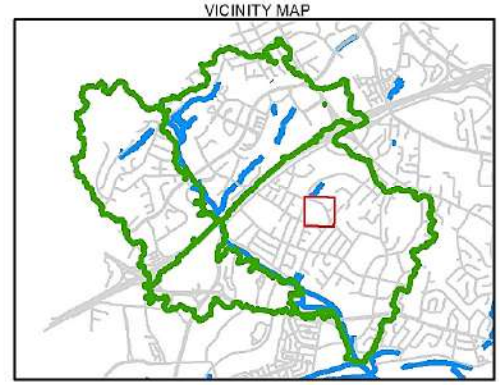
City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL



Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal)
Bioretention/Planters	17,362	208,348	129,870
Cisterns	10,650	10,650	6,639
Green/Blue Roofs	15,649	15,649	9,754
Porous Pavement	18,935	37,871	23,606
Total	**62,597**	**272,518**	**169,869**

VICINITY MAP



LEGEND
- Contours (ft)
- Parcels
- Watershed
- City of Alexandria Streams

Green Infrastructure Concepts
- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 55 110 220
Feet

James A. Polk Elem. School.

Green School

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

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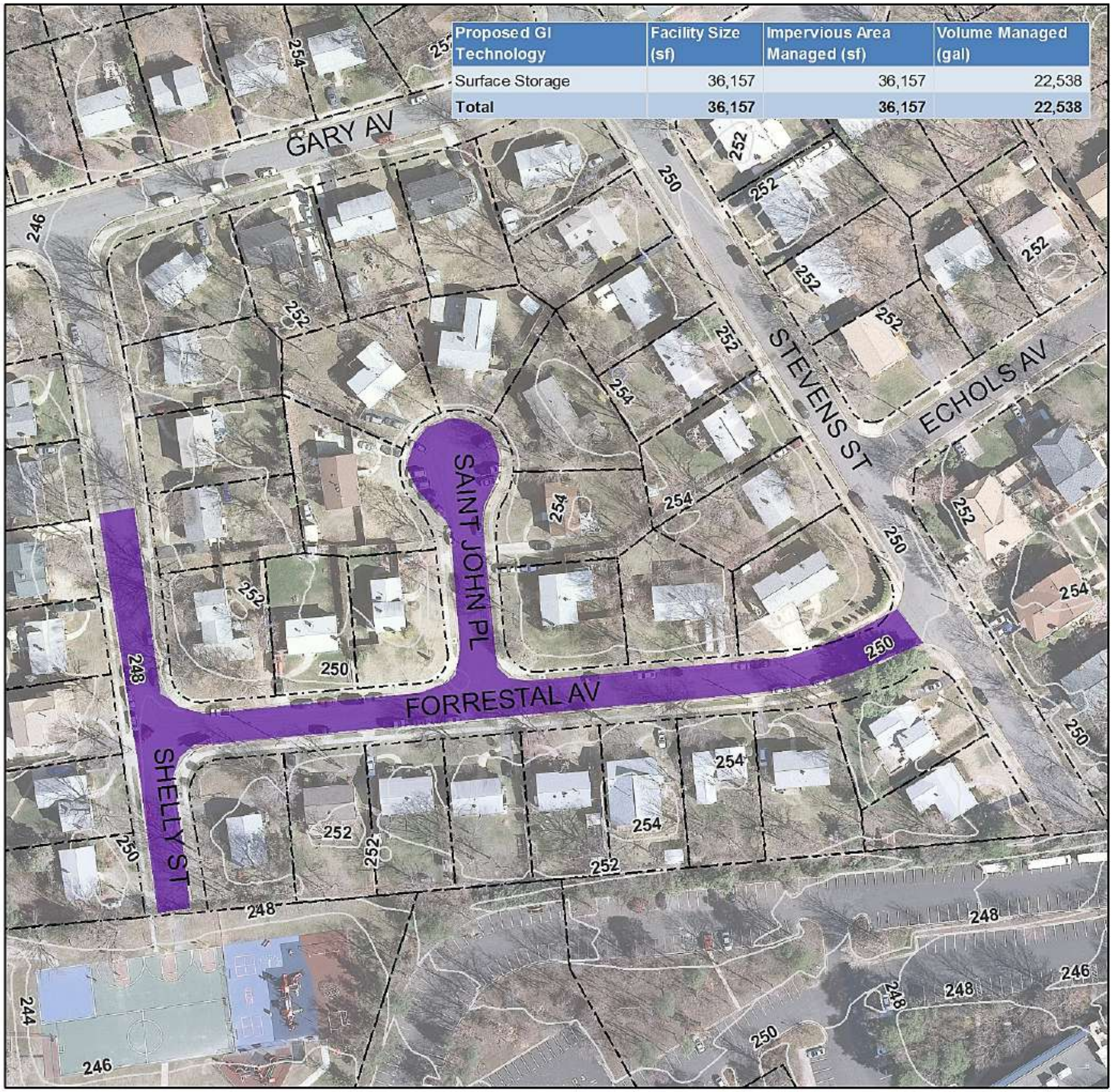
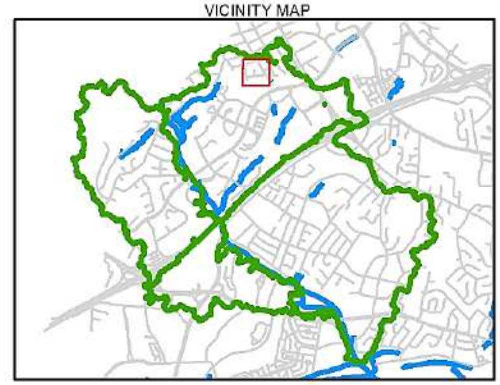


Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal)
Surface Storage	36,157	36,157	22,538
Total	**36,157**	**36,157**	**22,538**

VICINITY MAP



LEGEND

Contours (ft)

Parcels

Watershed

City of Alexandria Streams

Green Infrastructure Concepts

Bioretention/Planters

Cisterns

Green/Blue Roofs

Porous Pavement

Stream Daylighting

Surface Storage (Blue Streets)

N

0 50 100 200

Feet

Shirely Forest Residential Neighborhood

Blue/Green Street

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

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FACT SHEET: BIORETENTION AND STORMWATER PLANTERS

Rain garden in a public park setting in Lancaster, PA

Right-of-way bioretention planting in Syracuse, NY

Bioretention areas (often called Rain Gardens) are shallow surface depressions planted with specially selected native vegetation to treat and capture runoff and are sometimes underlain by sand or a gravel storage/infiltration bed. Bioretention is a method of managing stormwater by pooling water within a planting area and then allowing the water to infiltrate into the garden soils. In addition to managing runoff volume and mitigating peak discharge rates, this process filters suspended solids and related pollutants from stormwater runoff.

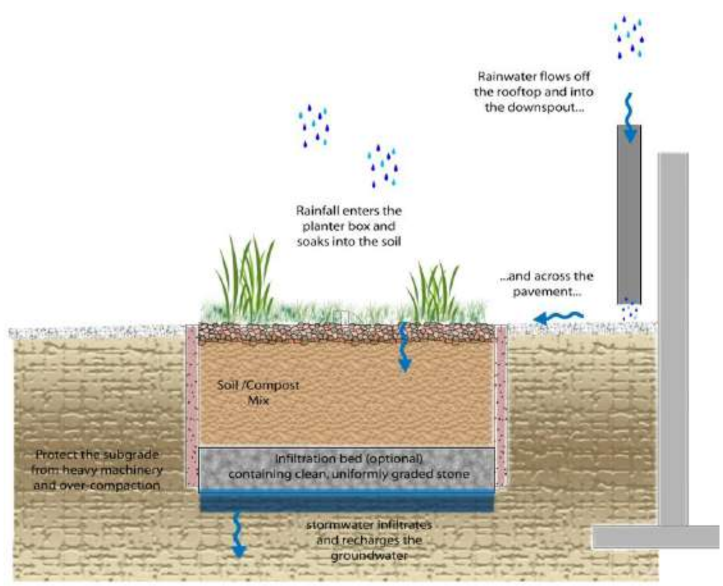
Bioretention can be designed into a landscape as a garden feature that helps to improve water quality while reducing runoff quantity. Rain Gardens can be integrated into a site with a high degree of flexibility and can balance nicely with other structural management systems including porous pavement parking lots, infiltration trenches, and non-structural stormwater BMPs. Bioretention areas typically require little maintenance once fully established and often replace areas that were intensively landscaped and required high maintenance.

A Stormwater Planter is a container or enclosed feature located either above ground or below ground, planted with vegetation that captures stormwater within the structure itself.

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile w/ broad applicability
- Enhanced site aesthetics and habitat
- Potential air quality & climate benefits

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Yes (Planters)
Industrial	Yes
Retrofit	Yes
Recreational	Yes
Public/Private	Yes



Conceptual cross-section showing planter with infiltration

VARIATIONS

- Subsurface storage/infiltration bed
- Use of underdrain and/or impervious liner
- Planters – Contained (above ground), infiltration (below ground), flow-through
- Pre-treatment incorporated into design

KEY DESIGN FEATURES

- Ponding depths 6 to 18 inches for drawdown within 48 hours
- Plant selection (native vegetation that is tolerant of hydrologic variability, salts, and environmental stress)
- Amended or engineered soil as needed
- Stable inflow/outflow conditions and positive overflow for extreme storm events
- Planters may require flow bypass during winter
- Planters - Captured runoff to drain out in 3 to 4 hours after storm even unless used for irrigation

SITE FACTORS

- Water Table/ Bedrock Separation: 2-foot minimum, 4-foot recommended (N/A for contained planter)
- Soils: HSG A and B preferred; C & D may require an underdrain (N/A for contained planter)
- Feasibility on steeper slopes: medium
- Potential Hotspots: yes with pretreatment and/or impervious liner, yes for contained planter
- Maximum recommended drainage area loading: 15:1; not more than 1 acre to one rain garden

MAINTENANCE

- Often requires watering during establishment
- Spot weeding, pruning, erosion repair, trash removal, mulch reapplication (as needed) required 2-3x/growing season
- Maintenance tasks and costs are similar to traditional landscaping

COST

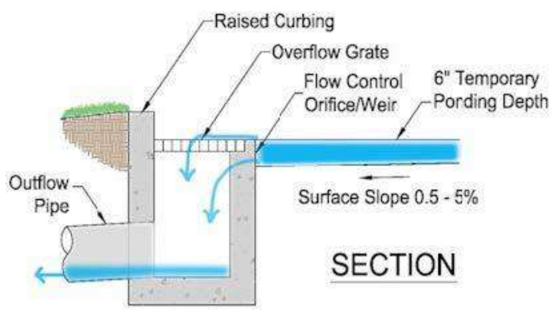
- Bioretention costs will vary depending on size/vegetation type/storage elements; typical costs $10-25/ sq. ft.

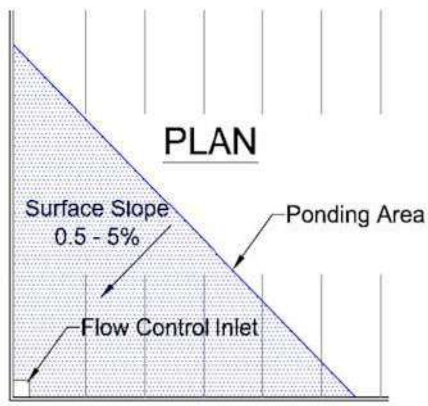
POTENTIAL LIMITATIONS

- Higher maintenance until vegetation is established
- Limited impervious drainage area to each BMP
- Requires careful selection & establishment of plants

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS	High	Capital Cost	Medium
Groundwater Recharge	High	TP	High	Maintenance	Low/Medium
Peak Rate	Medium	TN	Medium	Winter Performance	Medium
Erosion Reduction	Medium	Temperature	Medium/High	Fast Track Potential	Medium
Flood Protection	Medium			Aesthetics	High

FACT SHEET: BLUE STREETS





Blue streets refer to the practice of temporarily detaining stormwater, delaying its release and reducing its peak flow rate into the storm sewer system.

Surface storage practices have been used traditionally on rooftops (i.e. blue roofs) and in parking lots but can also be implemented in residential streets and right-of-ways with lower traffic volumes. These “blue streets” can be a cost-effective way to manage stormwater and address surcharging without significant subsurface excavation and construction interventions.

Surface storage is typically accomplished using drainage structures and retrofitting existing catch basins to feature devices such as orifice restrictors or vortex restrictors. Blue streets also emphasize minimizing the number of catch basins to the extent practical.

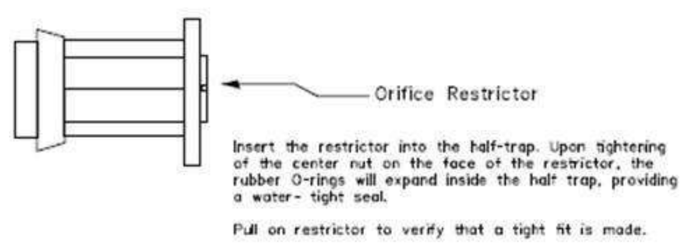
Blue streets (surface storage techniques) are often best implemented in alleys, low volume roads, and on private sites, for public perception and safety reasons.

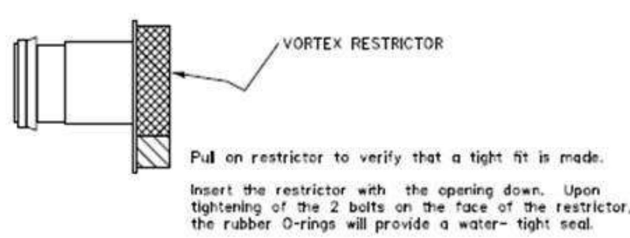
BENEFITS

- Reduces stress on drainage system
- Mitigates peak rate flow
- Cost-effective technique to manage stormwater
- Short duration storage
- Reduces need for subsurface excavation and construction

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Limited for Highway
Recreational	Yes
Public/Private	Yes/Yes

DRAINAGE STRUCTURES RESTRICTORS





Drainage structure restrictors are key features of surface storage and blue streets. Source: City of Chicago design manual

VARIATIONS

- Flow control structures
- Orifice restrictors
- Vortex restrictors
- Reduction in number of catch basins/inlets on a street

KEY DESIGN FEATURES

- Emergency overflows typically required
- Maximum ponding depths (less than one foot)
- Adequate surface slope to outlet
- Traffic volume, public safety, and user inconvenience must be taken into account

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – N/A
- Slope – Requires relatively low slopes to provide appreciable storage
- Potential hotspots – yes
- Maximum drainage area – relatively small DA to individual inlets (similar to conventional inlets)

MAINTENANCE

- Clean drainage structures and repair/replace parts as needed

COST

- Drainage structures restrictors range in cost, for example installing a vortex restrictor can be approximately $1000 per inlet

POTENTIAL LIMITATIONS

- Not suitable for heavily-used roadways without adequate median/shoulder space
- Excess ponding on roadways may freeze in winter conditions
- Public safety perceptions and concerns
- Does not inherently address water quality and quantity – should generally be combined with other BMPs

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low	TSS	Low	Capital Cost	Low
Groundwater Recharge	Low	TP	Low	Maintenance	Low/Medium
Peak Rate	Medium	TN	Low	Winter Performance	Medium
Erosion Reduction	Low	Temperature	Low	Fast Track Potential	High
Flood Protection	Medium			Aesthetics	Low

FACT SHEET: CISTERNS/RAIN BARRELS

Example of above-ground cistern with vegetation screening

Cisterns (or rain barrels) are structures designed to intercept and store runoff from rooftops to allow for its reuse, reducing volume and overall water quality impairment. Stormwater is contained in the cistern structure and typically reused for irrigation or other water needs. This GI technology reduces potable water needs while also reducing stormwater discharges.

Cisterns can be located above or below ground and are containers or tanks with a larger storage capacity than a rain barrel, and often used to supplement grey water needs (i.e. toilet flushing) in a building, as well as irrigation. Rain barrels are above-ground structures connected to rooftop downspouts that collect rainwater and store it until needed for a specific use, such as landscape irrigation.

Cisterns and rain barrels can be used in suburban and urban areas where the need for supplemental onsite irrigation or other high water uses is especially apparent.

BENEFITS

- Provides supplemental water supply
- Wide applicability
- Reduces potable water use
- Related cost savings and environmental benefits
- Reduces stormwater runoff impacts

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Yes, if demand exists
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Limited
Public/Private	Yes/Yes

Rain barrel prototype example

VARIATIONS

- Cisterns – can be either underground and above ground
- Water storage tanks
- Storage beneath a usable surface using manufactured stormwater products (chambers, pipes, crates, etc.)
- Various sizes, materials, shapes, etc.

KEY DESIGN FEATURES

- Small storm events are captured with most structures
- Provide overflow for large storms events
- Discharge/use water before next storm event
- Consider site topography, placing structure upgradient of plantings (if applicable) in order to eliminate pumping needs

SITE FACTORS

- Water table to bedrock depth – N/A (although must be considered for subsurface systems)
- Soils – N/A
- Slope – N/A
- Potential hotspots – typically N/A for rooftop runoff
- Maximum drainage area – typically relatively small, based on storage capacity

MAINTENANCE

- Use stored water and/or discharge before next storm event
- Clean annually and check for loose valves, leaks, etc. monthly during active season
- May require flow bypass valves or be taken offline during the winter

COST

- Cisterns typically cost from $3 to $8/gallon/ Rain Barrels range from $75 to $300 each

POTENTIAL LIMITATIONS

- Manages only relatively small storm events which requires additional management and use for the stored water.
- Typically requires additional management of runoff
- Requires a use for the stored water (irrigation, gray water, etc.)

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low/Medium	TSS	Medium	Capital Cost	Medium
Groundwater Recharge*	Low/Medium	TP	Medium	Maintenance	Medium
Peak Rate*	Low	TN	Low	Winter Performance	Low
Erosion Reduction	Low	Temperature	Low	Fast Track Potential	Medium/High
Flood Protection*	Low			Aesthetics	Low/Medium

**Although stand-alone cisterns are expected to have lower benefits in these categories, if combined with downspout disconnection to landscaped areas the benefits can be increased significantly.*

FACT SHEET: VEGETATED (GREEN) ROOFS AND BLUE ROOFS

Green roof (Philadelphia, PA)

Blue roof (NYC) / Photo – Gowanus Canal Conservancy

BENEFITS

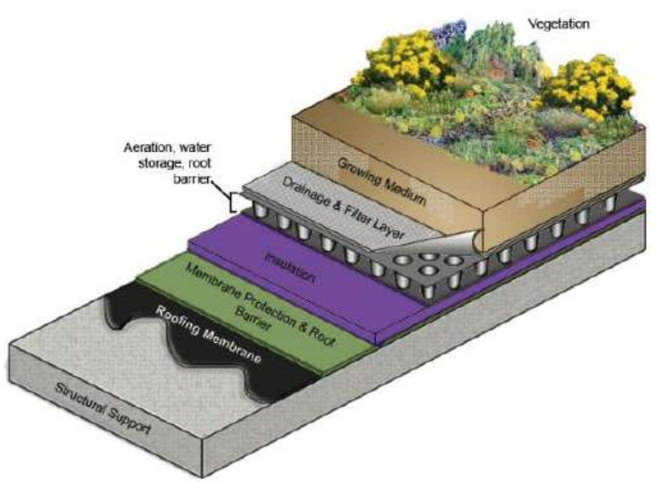
- High volume reduction (annual basis)
- Moderate ecological value and habitat (green roofs)
- High aesthetic value (green roofs)
- Energy benefits (heating/cooling)
- Urban heat island reduction

POTENTIAL APPLICATIONS	
Residential	Limited
Commercial	Yes
Ultra-Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Limited
Public/Private	Yes/Yes

A green roof is a veneer of vegetation that is grown on and covers an otherwise conventional flat or pitched roof, endowing the roof with hydrologic characteristics that more closely match surface vegetation. The overall thickness of the veneer typically ranges from 2 to 6 inches and may contain multiple layers, such as waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, and synthetic components. Vegetated roofs can be optimized to achieve water quantity and water quality benefits. Through the appropriate selection of materials, even thin vegetated covers can provide significant rainfall retention and detention functions.

Depending on the plant material and planned usage for the roof area, modern vegetated roofs can be categorized as systems that are intensive (usually > 6 inches of substrate), semi-intensive, or extensive (<4 inches). More maintenance, higher costs and more weight are the characteristics for the intensive system compared to that of the extensive vegetated roof.

Another GI rooftop technology - **Blue roofs -** are non-vegetated systems that employ stormwater control devices to temporarily store water on the rooftop and then release it into the drainage system at a relatively low flow rate. Storage can be provided by modifying roof drains or through the use of detention trays that sometimes have a lightweight gravel media. Blue roof and green roof technologies can also be combined in a design to achieve



Cross-section showing components of vegetated roof system

VARIATIONS

- Green roofs - single media system, dual media system (with synthetic liner)
- Green roofs - Intensive, Extensive, or Semi-intensive

KEY DESIGN FEATURES

- Engineered media should have a high mineral content and is typically 85% to 97% nonorganic.
- 2-6 inches of non-soil engineered media; assemblies that are 4 inches and deeper may include more than one type of engineered media.
- Irrigation is generally not required (or even desirable) for optimal stormwater management
- Internal building drainage, including provision to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the vegetated roof system.
- Assemblies planned for roofs with pitches steeper than 2:12 (9.5 degrees) must incorporate supplemental measures to insure stability against siding.
- The roof structure must be evaluated for compatibility with the maximum predicted dead and live loads. Typical dead loads for wet extensive vegetated covers range from about 12 to 36 pounds per square foot.
- Waterproofing must be resistant to biological and root attack. In many instances a supplemental root barrier-layer is installed to protect the primary waterproofing.
- Blue roofs: roof structure, waterproofing, accommodation for larger storm events/emergency overflows

MAINTENANCE

- Once vegetation is fully established, little maintenance needed for the extensive system
- Maintenance cost is similar to native landscaping, $0.10-$0.35 per square foot
- Blue roof maintenance is similar to conventional roof maintenance (cleaning roof and drains as necessary)

COST

- Green roofs: $10 - $35 per square foot, including all structural components, soil, and plants; more expensive than traditional roofs, but have longer lifespan; generally less expensive to install on new roof versus retrofit on existing roof
- Blue roofs: Typically add only $1-$5 per square foot compared to traditional roofs

POTENTIAL LIMITATIONS

- Green roofs have higher maintenance needs until vegetation is established
- Need for adequate roof structure and waterproofing; can be challenging on retrofit application

STORMWATER QUANTITY FUNCTIONS*		STORMWATER QUALITY FUNCTIONS*		ADDITIONAL CONSIDERATIONS	
Volume	Medium/High	TSS	Low/Medium	Capital Cost	High
Groundwater Recharge	Low	TP	Low/Medium	Maintenance	Medium
Peak Rate	Medium	TN	Low	Winter Performance	Medium
Erosion Reduction	Low/Medium	Temperature	Medium	Fast Track Potential	Low
Flood Protection	Low/Medium			Aesthetics	High

**For green roofs, blue roofs primarily function for peak rate control and flood protection.*

FACT SHEET: POROUS PAVEMENT

Porous asphalt basketball courts (Lancaster, PA)

Porous (pervious) pavement is a Green Infrastructure (GI) technique that combines stormwater infiltration, storage, and a structural pavement consisting of a permeable surface underlain by a storage/infiltration bed. Porous pavement is well suited for parking areas, walking paths, sidewalks, playgrounds, plazas, basketball courts, and other similar uses.

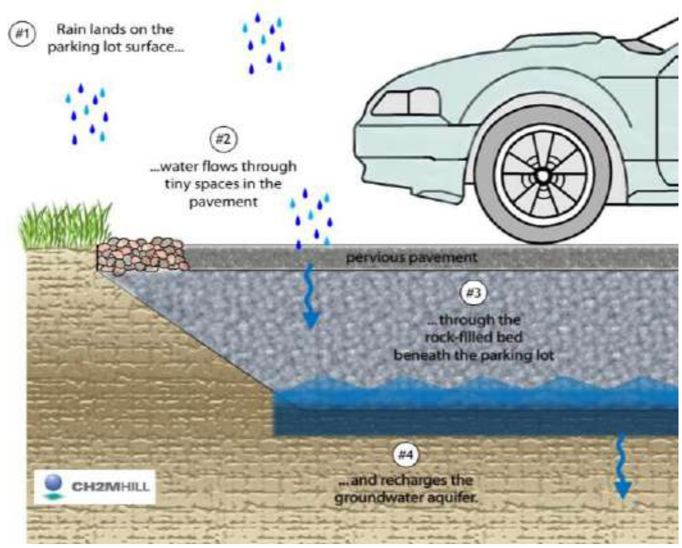
A porous pavement system consists of a pervious surface course underlain by a storage bed, typically placed on uncompacted subgrade to facilitate stormwater infiltration. The subsurface storage reservoir may consist of a stone bed of uniformly graded, clean and washed course aggregate with a void space of approximately 40% or other manufactured structural storage units. Porous pavement may be asphalt, concrete, permeable paver blocks, reinforced turf/gravel, or other emerging types of pavement.

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile with broad applicability
- Dual use for pavement structure and stormwater management
- Pavers come in range of sizes and colors
- Opportunity for public education/demonstration

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Limited
Retrofit	Yes
Highway	Limited
Recreational	Yes
Public/Private	Yes/Yes

Porous pavers (San Diego)



Conceptual diagram showing how porous pavement functions

KEY DESIGN FEATURES

- Soil testing required for infiltration designs
- Limit amount of adjacent areas that drain directly onto the surface of the porous pavement
- Uncompacted soil subgrade for infiltration
- Level storage bed bottoms
- Provide positive storm water overflow from bed
- Surface permeability greater than 20 inches per hour
- Secondary inflow mechanism recommended
- Pretreatment for sediment-laden runoff, limit sources of sediment/debris deposition

SITE FACTORS

- Water Table/Bedrock Separation: 2-foot minimum
- Soils: HSG A&B preferred; HSG C&D may require underdrains
- Feasibility on steeper slopes: Low
- Potential Hotspots: Not without design of pretreatment system/impervious liner

MAINTENANCE

- Clean inlets
- Vacuum biannually
- Maintain adjacent landscaping/planting beds
- Periodic replacement of aggregate in paver block joints (if applicable)
- Careful winter maintenance (no sand or other abrasives, careful plowing)

COST

- Varies by porous pavement type
- Local quarry needed for stone filled infiltration bed
- Typically $7-$15 per square foot, including underground stormwater storage bed
- Generally more than standard pavement, but saves on cost of other BMPs and traditional drainage infrastructure

POTENTIAL LIMITATIONS

- Careful design & construction required
- Pervious pavement not suitable for all uses/not suitable for steep slopes
- Higher maintenance needs than standard pavement

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS*	High	Capital Cost	Medium
Groundwater Recharge	High	TP	High	Maintenance	Medium
Peak Rate	Medium/High	TN	Medium	Winter Performance	Medium/High
Erosion Reduction	Medium/High	Temperature	High	Fast Track Potential	Low/Medium
Flood Protection	Medium/High			Aesthetics	Low to High

** While porous pavements typically result in low TSS loads, sources of sediment should be minimized to reduce the risk of clogging.*

FACT SHEET: SOIL AMENDMENTS

Healthy soils help vegetation thrive while also increasing soil infiltration rates Photo: S.Coronado

Soil amendments can include a variety of practices that reduce the generation of runoff by improving vegetation growth, increasing water infiltration, and improving water holding capacity. For example, on existing turf grass, soil amendments can include placing a thin layer of compost or other materials and spreading them evenly over existing vegetation. Amendments on existing turf grass areas can be applied for several years to improve soil over time. Soil testing can indicate how many applications are appropriate. Existing grass areas can also be aerated to improve water transmission and allow for deeper incorporation of compost.

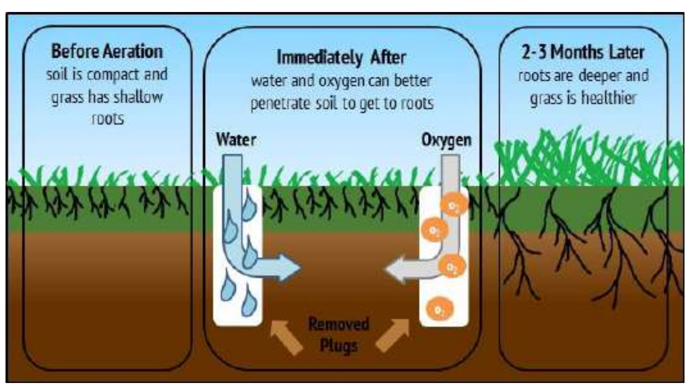
On new construction, redevelopment, and restoration projects, compost can be applied and deeply tilled into compacted soils to restore their porosity before the areas are re-vegetated (potentially with native landscaping, combining the benefits of both GI strategies).

BENEFITS

- Enhanced soil health and vegetation growth/root depth
- Improved soil infiltration rates
- Enhanced soil water holding capacity
- Reduced stormwater runoff from soil surface

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Yes
Recreational	Yes
Public/Private	Yes/Yes

A variety of soil amendments are available depending on the specific soil conditions and desired result. Photo: Pahls Market



Physical aeration (tilling) can also help improve soil health and soil permeability/porosity. Image: GreenMaxLawns

VARIATIONS

- Treating turf grass or areas with more intensive plant palettes
- Combining amended soil areas with downspout disconnection
- Physical aeration/tilling of turf grass/vegetated areas can help to remedy soil compaction
- Compost, sand, microbes, mycorrhizae, gypsum, biochar, manure, worm castings, etc.
- Amendments can improve soil aggregation, increase porosity, and improve aeration and rooting depth

KEY DESIGN FEATURES

- Soil bulk density and soil nutrient testing required
- Existing soil conditions should be evaluated before forming an amendment strategy

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – Bulk density and nutrient levels
- Slope – Not recommended for use on slopes greater than 3:1
- Potential hotspots – N/A
- Maximum drainage area – N/A

MAINTENANCE

- Replenishment of amendments on a regular basis may be required
- Aeration of soil often done at same time

COST

- The cost of soil amendments ranges widely depending on the size and type. Larger projects are estimated to cost approximately $5,000 per acre.

POTENTIAL LIMITATIONS

- Viability depends upon soil testing results
- Certain types of soil may not be favorable for success with amendments
- Not a regulated industry – testing of amendment may be needed to ensure specifications
- Physical aeration should not be done near existing tree roots

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS*	Medium	Capital Cost	Low
Groundwater Recharge	Medium	TP*	Medium	Maintenance	Low/Medium
Peak Rate	Medium	TN*	Medium	Winter Performance	Medium
Erosion Reduction	High	Temperature	Low	Fast Track Potential	Medium
Flood Protection	Low/Medium			Aesthetics	Medium

**Water quality benefits expected to vary widely depending on the condition of the soil/landscape prior to soil amendments.*

Appendix D
Alternatives Analysis Results

Appendix D - Alternative Analysis Summary

Tabulation of solutions, costs, and scoring for all projects in Holmes Run

		Solution Summary			Flood Volume Summary					Weighted Solution Score								
Problem Area ID	Solution Technology (Conveyance, Storage, Low GI, Medium GI, High GI)	Project Name	Cost ($M)	Benefit-Cost Ratio	Existing Flood Volume (MG)	Solution Flood Volume (MG)	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)	Urban Drainage/ Flooding	Environmental Compliance	EcoCity Goals/ Sustainability	Social Benefits	Integrated Asset Management	City-Wide Maintenance Implications	Constructability	Public Acceptance	Total
301	Low GI	LGI-301	$ 0.086	614.4	0.19	0.17	0.02	13%	$ 3.46	2.2	2.5	7.2	5.8	6.6	13.0	10.8	4.8	53.0
301	Medium GI	MGI-301	$ 0.435	164.9	0.19	0.12	0.08	39%	$ 5.79	6.7	16.8	7.2	5.8	6.6	13.0	10.8	4.8	71.7
301	High GI	HGI-301	$ 0.800	90.9	0.19	0.06	0.13	67%	$ 6.24	11.5	13.0	7.2	5.8	6.6	13.0	10.8	4.8	72.7
301	Conveyance	CONV-301	$ 1.115	44.1	0.19	-	0.19	100%	$ 5.83	17.1	0.0	0.0	0.0	6.6	16.2	4.3	4.8	49.1
302	Low GI	LGI-302	$ 0.293	159.6	0.27	0.22	0.05	17%	$ 6.19	3.0	1.9	3.6	2.9	6.6	13.0	10.8	4.8	46.7
302	Medium GI	MGI-302	$ 1.475	45.4	0.27	0.14	0.13	49%	$ 11.07	8.5	16.8	3.6	2.9	6.6	13.0	10.8	4.8	67.0
302	High GI	HGI-302	$ 2.714	23.9	0.27	0.06	0.21	78%	$ 12.93	13.3	9.8	3.6	2.9	6.6	13.0	10.8	4.8	64.9
302	Conveyance	CONV-302	$ 3.330	12.1	0.27	-	0.27	100%	$ 12.31	17.1	0.0	0.0	0.0	0.0	16.2	2.2	4.8	40.3
302	Storage	STOR-302	$ 0.225	80.4	0.27	0.18	0.09	33%	$ 2.49	5.7	0.0	0.0	0.0	0.0	3.2	4.3	4.8	18.1
303	Low GI	LGI-303	$ 0.064	645.0	0.18	0.14	0.04	22%	$ 1.62	3.9	2.1	3.7	2.9	0.0	13.0	10.8	4.8	41.2
303	Medium GI	MGI-303	$ 0.322	182.3	0.18	0.11	0.07	39%	$ 4.67	6.7	16.8	3.7	2.9	0.0	13.0	10.8	4.8	58.8
303	High GI	HGI-303	$ 0.593	93.6	0.18	0.08	0.10	55%	$ 6.08	9.5	10.7	3.7	2.9	0.0	13.0	10.8	4.8	55.5
303	Conveyance	CONV-303	$ 0.501	97.7	0.18	-	0.18	100%	$ 2.85	17.1	0.0	0.0	0.0	0.0	16.2	10.8	4.8	49.0
304	Low GI	LGI-304	$ 0.160	287.7	0.79	0.69	0.10	13%	$ 1.54	2.3	1.7	3.8	3.1	6.6	13.0	10.8	4.8	46.1
304	Medium GI	MGI-304	$ 0.808	78.3	0.79	0.59	0.20	26%	$ 3.98	4.4	16.8	3.8	3.1	6.6	13.0	10.8	4.8	63.3
304	High GI	HGI-304	$ 1.485	38.7	0.79	0.48	0.31	39%	$ 4.84	6.7	8.7	3.8	3.1	6.6	13.0	10.8	4.8	57.5
304	Conveyance	CONV-304	$ 2.810	15.1	0.79	0.00	0.78	99%	$ 3.58	17.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	42.4
305	Low GI	LGI-305	$ 0.451	101.8	0.95	0.85	0.10	11%	$ 4.39	1.9	2.3	3.6	2.9	6.6	13.0	10.8	4.8	46.0
305	Medium GI	MGI-305	$ 2.276	28.8	0.95	0.56	0.39	41%	$ 5.80	7.1	16.8	3.6	2.9	6.6	13.0	10.8	4.8	65.6
305	High GI	HGI-305	$ 4.187	15.6	0.95	0.31	0.64	68%	$ 6.52	11.6	11.9	3.6	2.9	6.6	13.0	10.8	4.8	65.3
305	Conveyance	CONV-305	$ 2.675	14.0	0.95	0.64	0.30	32%	$ 8.80	5.5	0.0	0.0	0.0	6.6	16.2	4.3	4.8	37.5
306	Low GI	LGI-306	$ 0.069	451.5	0.30	0.28	0.01	5%	$ 4.79	0.8	2.6	3.2	2.5	0.0	13.0	4.3	4.8	31.3
306	Medium GI	MGI-306	$ 0.349	136.9	0.30	0.24	0.06	19%	$ 6.21	3.3	16.8	3.2	2.5	0.0	13.0	4.3	4.8	47.8
306	High GI	HGI-306	$ 0.643	73.7	0.30	0.19	0.10	35%	$ 6.24	6.0	13.6	3.2	2.5	0.0	13.0	4.3	4.8	47.3
306	Conveyance	CONV-306	$ 0.662	60.8	0.30	0.00	0.29	99%	$ 2.25	17.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	40.2
307	Low GI	LGI-307	$ 0.265	165.0	0.60	0.43	0.17	29%	$ 1.53	5.0	2.7	4.1	3.3	0.0	13.0	10.8	4.8	43.7
307	Medium GI	MGI-307	$ 1.335	45.1	0.60	0.34	0.26	43%	$ 5.13	7.5	16.8	4.1	3.3	0.0	13.0	10.8	4.8	60.3
307	High GI	HGI-307	$ 2.456	24.4	0.60	0.25	0.35	59%	$ 6.97	10.1	13.8	4.1	3.3	0.0	13.0	10.8	4.8	59.9
307	Conveyance	CONV-307	$ 2.698	18.2	0.60	-	0.60	100%	$ 4.50	17.1	0.0	0.0	0.0	0.0	16.2	10.8	4.8	49.0
308	Low GI	LGI-308	$ 0.174	221.2	0.24	0.24	0.00	1%	$ 72.13	0.2	2.9	3.8	3.0	6.6	13.0	4.3	4.8	38.6
308	Medium GI	MGI-308	$ 0.879	65.7	0.24	0.16	0.08	32%	$ 11.44	5.5	16.8	3.8	3.0	6.6	13.0	4.3	4.8	57.8
308	High GI	HGI-308	$ 1.618	38.1	0.24	0.09	0.15	63%	$ 10.77	10.8	15.3	3.8	3.0	6.6	13.0	4.3	4.8	61.6
308	Conveyance	CONV-308	$ 1.401	33.5	0.24	-	0.24	100%	$ 5.86	17.1	0.0	0.0	0.0	6.6	16.2	2.2	4.8	46.9
309	Low GI	LGI-309	$ 0.209	173.8	1.69	1.57	0.12	7%	$ 1.72	1.2	3.3	5.3	4.3	0.0	13.0	4.3	4.8	36.3
309	Medium GI	MGI-309	$ 1.052	50.3	1.69	1.25	0.43	26%	$ 2.42	4.4	16.8	5.3	4.3	0.0	13.0	4.3	4.8	52.9
309	High GI	HGI-309	$ 1.935	29.1	1.69	0.92	0.77	46%	$ 2.51	7.8	16.8	5.3	4.3	0.0	13.0	4.3	4.8	56.3
309	Conveyance	CONV-309	$ 0.250	195.7	1.69	-	1.69	100%	$ 0.15	17.1	0.0	0.0	0.0	0.0	16.2	10.8	4.8	49.0

Appendix E
Basis of Cost

TECHNICAL MEMORANDUM

City of Alexandria Storm Sewer Capacity Analysis

Planning Level Cost Information

PREPARED FOR:	City of Alexandria Transportation and Engineering Services
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	May 15, 2014
PROJECT NUMBER:	240027

Introduction

The City of Alexandria, Virginia, has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. The watersheds include Hooffs Run, Four Mile Run, Holmes Run, Cameron Run, Taylor Run, Strawberry Run, Potomac River, and Backlick Run.

This technical memorandum provides details on the basis of cost estimates developed for each solution and the watershed wide alternatives. The information includes panning level unit cost for conveyance, storage and green infrastructure solutions.

These cost estimates are considered a Class 4 - Planning Level estimate as defined by the American Association of Cost Engineering (AACE), International Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. It is considered accurate to +50% to -30% based up to a 15% complete project definition.

Definitions

The following cost terminologies are used within this technical memorandum:

- Construction cost: Installed cost, including materials, labor, and site adjustment factors such as overcoming utility conflicts, dewatering, and pavement restoration.
- ENRCCI Cost Adjustment Factor: Cost adjustment factor of 0.9 to adjust cost to October 2013 dollars for the DC-Baltimore metro area
- Service and Contingency Factor (SCF) A factor of 1.4 is applied for this project to account for engineering and design expenses (20%) and for contingency allowance (20%).
- Capital cost: Construction cost multiplied by a Service and Contingency Factor (SCF) to cover engineering and design and contingency allowance.
- Operating cost: Operation and maintenance were not considered for this project.

Gravity Sewer Relief Costs

Conveyance projects were costed on a per linear foot basis, based on pipe size and depth. The construction cost rates ($/ft) for gravity sewer replacement are listed in Table 1. Cost rates are shown for different road types. The Gravity sewer cost rates include complete installation of sewer pipes, inlets/manholes, and other ancillary structures as well as surface restoration. The costs were established through literature review and updated based on an assessment of bid tabulation data from Kansas City metro area between 2008 and 2012, and a comparison to Fairfax County, VA unit cost schedule, March 2013. All costs were adjusted to Washington DC, 2013 dollars using Engineering News-Record Construction Cost Index (ENRCCI) adjustment factors.

Factors are applied to the construction cost of gravity sewer pipe replacement to reflect the cost associated with crossing under streams and railroads as listed in Table 2.

Costs of routine O&M, inspection and cleaning at periodic intervals during the life of the gravity sewer were assumed to part of City-wide facilities maintenance plan and should take place even though those costs are not specifically included here.

TABLE 1
Open Cut Gravity Sewer Construction Costs

		Sewer Construction Cost ($/LF) (1)					
		Trench depth up to 10 feet		Trench depth 10 to 15 feet		Trench depth 15 to 20 feet	
Pipe Diameter (in)	Material	Residential	Arterial	Residential	Arterial	Residential	Arterial
8	PVC	$90	$104	$113	$130	$140	$162
10	PVC	$113	$131	$140	$163	$176	$204
12	PVC	$122	$140	$152	$175	$190	$218
15	PVC	$131	$153	$163	$192	$204	$239
18	PVC	$140	$162	$175	$203	$218	$253
21	PVC	$162	$189	$203	$237	$253	$295
24	PVC	$185	$212	$230	$265	$288	$330
30	RCP	$257	$297	$320	$372	$401	$464
36	RCP	$306	$356	$383	$445	$478	$555
42	RCP	$360	$414	$450	$518	$563	$647
48	RCP	$410	$473	$512	$590	$640	$738
54	RCP	$459	$531	$574	$664	$717	$830
60	RCP	$509	$585	$635	$732	$795	$914
72	RCP	$815	$936	$1,018	$1,170	$1,273	$1,463

(1) Listed construction costs have been adjusted to October 2013 dollars using ENRCCI for the DC-Baltimore Metro area.

TABLE 2
Gravity Pipe Construction Cost Factors

Type of Crossing	Cost Factor
Stream	3
Railroad	7

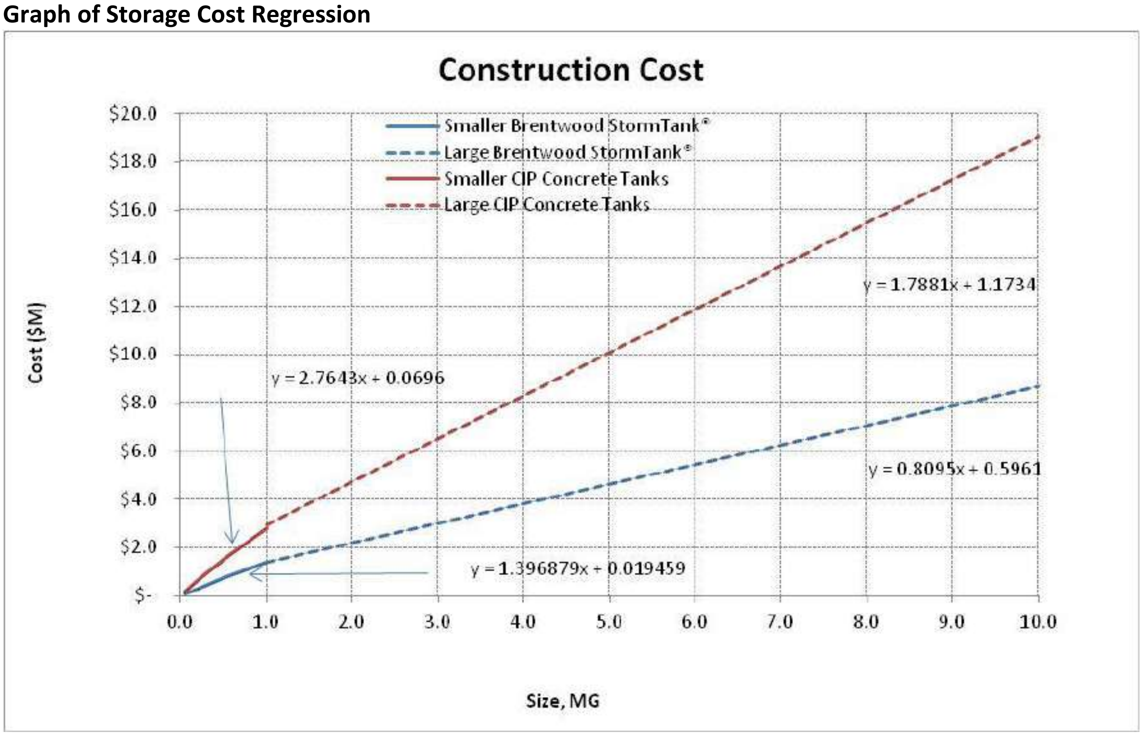
Storage Facility Cost Information

Cost estimates for the storage facilities were developed for two technologies: A traditional underground cast-in-place concrete tank and an alternative stackable modular unit installed underground and wrapped with an impermeable or permeable liner.

The CIP Concrete storage facility construction cost was developed as a customized cost estimate based on CH2M HILL's Program Alternative Cost Calculator (PACC) Tool. The costs are construction costs only and do not include administration costs, engineering costs, contingencies, and other soft costs. The costs for smaller storage units with volumes less than 1 million gallon were found to be high for the CIP concrete tank. Hence, a separate takeoff cost estimate was developed for smaller storage volume; less than 1 million gallons.

A separate cost estimate was developed for the stackable modular units. There is an increasing use of these technologies in the industry and the cost of installation is getting increasingly competitive compared to traditional storage methods. Construction costs were developed based on one such stackable modular unit, StormTank® modules by Brentwood Industries. The cost for the Brentwood StormTank® modules came out significantly less than that for CIP concrete tanks. For the purpose of the evaluation of watershed wide alternative solutions, the StormTank® modules was used as the most cost effective alternative, however site specific conditions will determine which technology will be most appropriate in a given location. For example a site with high water table may make the use of CIP concrete tanks preferable over the StormTank® modules. The estimated construction costs for the CIP concrete tanks and the Brentwood StormTank® are provided in Figure 1.

FIGURE 1
Graph of Storage Cost Regression



The following assumptions were made for storage tank selection and sizing:

1. Offline enclosed underground storage will be active only during wet weather events.
2. Options for odor control were not considered.
3. Costs for storage facilities with intermediate storage volumes were interpolated based on linear regression shown in Figure 1.

Green Infrastructure (GI) Cost Information

A variety of sources and professional judgment were used to develop the GI costs. Where technologies were directly comparable, costs were updated based on Fairfax County, VA unit cost schedule, March 2013. The unit costs used to develop GI implementation cost are included in Table 4. Costs reflecting stand-alone projects (e.g., installing a green roof on top of an existing building) were used for costing alternatives solutions. Incremental costs of adding GI to an existing project can provide significant savings and are provided for reference, but not used directly in cost estimates for this project.

In the CASSCA Project GI is being proposed as a series of GI programs applicable to specific land uses (e.g. green parking is applicable to parking lots). Each GI program may consist of multiple GI technologies which drive the cost of implementing that program. Table 5 lists and the relative amounts of area designated for the GI technologies assumed to be part of each GI program and the resultant unit cost for each GI program.

TABLE 4
Unit Construction Costs of Green Infrastructure Technologies

Green Technology	Stand Alone Cost Proposed for GI Plan ($/GI acre)	Loading Ratio (Ratio of Area Managed to Area of GI)	Stand-Alone Cost Proposed for GI Plan ($/acre managed)	Incremental GI Cost Compared to Stand-Alone
Native Landscaping/Soil Amend.	$ 5,000	1	$ 5,000	50%
Rain Barrels[1] and Native Landscaping/Soil Amend.	$ -	N/A	$ 15,000	90%
Cisterns[2]	N/A	N/A	$ 34,000	90%
Blue Street/Inlet control devices	N/A	N/A	$ 22,500	N/A
Rain Gardens	$ 436,000	12	$ 36,000	70%
Stormwater Trees[3]	$ 34,700	0.5	$ 69,000	50%
Bioswale/Bioretention	$ 1,045,000	12	$ 87,000	70%
Porous Pavement/ Infiltration Trench	$ 436,000	4	$ 109,000	70%
Green Roof[4]	$ 501,000	1	$ 501,000	43%

[1] Each rain barrel is assumed to manage 350 ft^2 of rooftop; therefore, 124.5 barrels are required for 1 acre of roof.
[2] Each 1000-gallon cistern is assumed to manage 6,500 ft^2 of impervious area; therefore, 6.7 barrels are required for 1 acre.
[3] Trees are assumed to have an average 10-foot canopy radius (314 ft^2), with 50 percent assumed to be overhanging impervious area.
[4] Incremental cost of green roofs set to 43 percent to match the District's $5/ ft^2 ($217,800/acre) green roof incentive program.

TABLE 5
Green Infrastructure Technology Elements and Unit Construction Cost of Each Green Program

	% Area of Program Assigned to Each GI Technology						
Green Technology	**Blue Streets**	**Green Alley**	**Green Buildings**	**Green Parking**	**Green Roofs**	**Green Schools**	**Green Schools**
Native Landscaping/Soil Amend.	-	-		-	-	-	-
Rain Barrels[1] and Native Landscaping/Soil Amend.	-	-	30%	-	-	-	-
Cisterns	-	-	10%	-	-	-	-
Blue Street/Inlet control devices	100%					-	-
Rain Gardens	-	-	30%	-	-	-	-
Stormwater Trees	-	-		-	-	-	30%
Bioswale/Bioretention	-	-	30%	50%	-	65%	30%
Porous Pavement/ Infiltration Trench	-	100%		50%	-	30%	40%
Green Roof	-	-	-	-	100%	5%	-
Unit Cost ($/acre managed)	**$22,500**	**$109,000**	**$44,800**	**$98,000**	**$501,000**	**$114,300**	**$90,400**

Three levels of green infrastructure implementation were evaluated for this project:

- High Implementation – Manage 50% of total impervious area in the shed
- Medium Implementation – Manage 30% of total impervious area in the shed
- Low Implementation – Manage 10% of total impervious area in the shed

The unit cost of implementing GI at the various implementation levels is driven by the availability of GI opportunity areas. As the area available to achieve a GI implementation level become scarce, the cost to achieve that level on GI implementation also increases. It was assumed that GI implementation would focus, in succession, from the most to the least cost effective programs and technologies. That is, for each level of GI implementation the most cost effective program and technologies would be implemented first until the available opportunities for those programs are exhausted. If the level of implementation is not achieved with the most cost effective program, the next most cost effective program is considered in that order until the desired level of GI implementation is achieved. Therefore Low Implementation would be more cost effective (lower cost per acre managed). The unit cost for each implementation level was computed separately for each watershed based on the cost information presented above and the distribution of areas available for GI implementation.

Green Opportunities

Opportunities for blue streets, green streets and alleys, green buildings, green parking, green roofs, and green schools were identified by completing a desktop analysis using the City's 2011 basemap data, including:

- Roads (Road_y and Road_lc)
- Buildings (Blds_y)
- Parking lots (Parking_y)
- Zoning (Zoning_y)
- Parcels (Parcels_y)

The approach to identifying potential opportunities for each program is provided below. All opportunities were combined into a single shapefile of polygons with an attribute for area calculated in acres.

Blue Streets

Local or Residential roads with an average slope less than or equal to 1% and a maximum slope less than or equal to 3%. Road slope was estimated using ArcGIS 3D Analyst tools and the Road_lc feature and City of Alexandria DEM as inputs.

Green Streets and Alleys

Green streets and alleys were identified using the Road_lc and Road_y features to identify roads classed as Arterial, Primary Collector, Residential Collector, Local, and Alley with an average slope less than or equal to 5%. Roadways that fall within school parcels were removed from this layer because they are included in the Green Schools program. Road slope was estimated using ArcGIS 3D analyst tools and the Road_lc feature and City of Alexandria DEM as inputs.

Green Buildings

Green buildings opportunities include buildings where disconnection may be possible. Based on a windshield survey of Taylor Run, approximately 50% of residential buildings, not including single family detached homes, may have opportunities for downspout disconnection. To identify these opportunities, buildings with a BUSE of '1-Residential' were selected from the Blds_y features to identify all residential buildings. This selection was narrowed to apartment buildings and larger residential developments, removing detached houses (BTYPE = 'Detached house'), buildings with less than 5 units (BUNITS < 5), as well as removing nursing homes, hotels, and detention centers. Residential buildings on school properties were also removed because those are accounted for in the Green Schools program. Buildings with a footprint greater than 20,000 square feet were also removed because these buildings are likely too large for a disconnection program.

The footprint of the final selection was reduced by approximately 50% (based on the result of the Taylor Run windshield survey) to approximate the total area of impervious surfaces that could potentially be managed through a disconnection program.

Green Parking

Green parking opportunities were identified as parking lots in the Parking_y feature class with a parking area over 3,000 square feet. Parking lots on school parcels were removed from this selection because they are accounted for in the Green Schools program.

Green Roofs

Green roof opportunities were identified by selecting buildings in the Blds_y feature class with a footprint over 20,000 ft^2 that have a building use (BUSE) of Commercial, Industrial, Institution, Transportation, and Multiple or Mixed use. Also included were buildings over 20,0000 ft^2 that were within a Commercial, Industrial, Coordinated Development District, or Mixed Use zone based on the Zoning_y feature class, unless those buildings were garage/sheds. Buildings on school parcels were removed from this selection because they are accounted for in the Green Schools program.

Green Schools

School parcels were identified by selecting all parcels with a land description (LANDDESC) of 'ED. PUBLIC SCHOOLS', 'PRIVATE ED ENSTS.', or 'ST. ED. INSTITUTIONS' or with an owner name or address that indicated it was school property. School buildings with potential for green roofs were identified by selecting all buildings on school parcels or buildings in the Blds_y features with the word 'school' in the building name (BNAME) or building campus (BCAMPUS) fields where the footprint is over 3,000 ft^2. All remaining impervious surfaces on the school parcels (roads, sidewalks, small buildings, recreation facilities, etc.) were identified as opportunities for green schools.